Issued February 3, 1913.

U. S. DEPARTMENT OF AGRICULTURE,

FOREST SERVICE—BULLETIN 121.

HENRY S. GRAVES, Forester.

FORESTATION OF THE SAND HILLS OF NEBRASKA AND KANSAS.

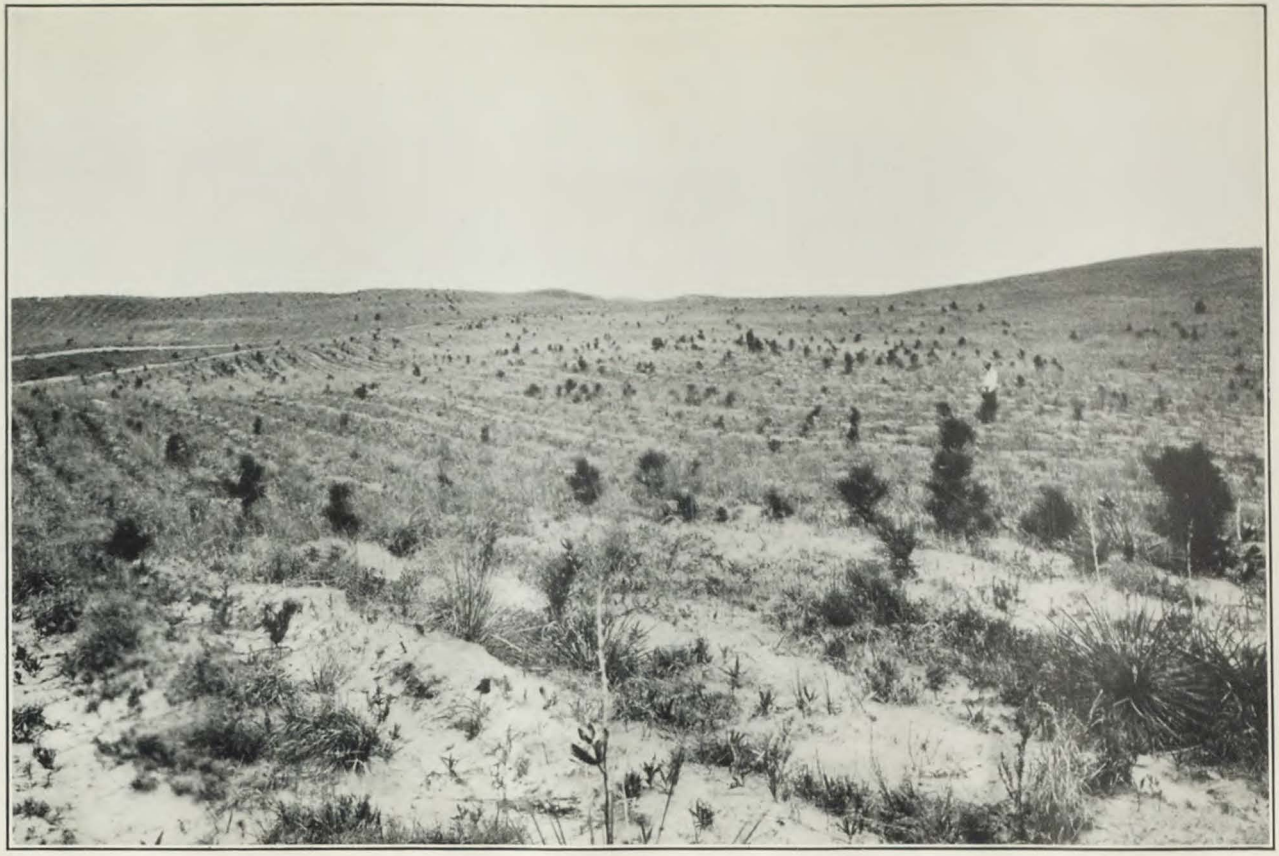
BY

CARLOS G. BATES, Forest Assistant,

AND

ROY G. PIERCE, Deputy Supervisor.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1913.



YOUNG WESTERN YELLOW PINES, ESTABLISHED IN THE NEBRASKA SAND HILLS SINCE 1904.

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FOREST SERVICE.

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NEBRASKA NATIONAL FOREST.

R. G. PIERCE, *Deputy Supervisor.*

LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Forest Service,
Washington, D. C., September 3, 1912.

Sir: I have the honor to transmit herewith a manuscript entitled "Forestation of the Sand Hills of Nebraska and Kansas," by Carlos G. Bates, in charge of investigative work, District 2, and Roy G. Pierce, Deputy Supervisor of the Nebraska National Forest, and to recommend its publication as Bulletin 121 of the Forest Service.

Respectfully, Henry S. Graves,
Forester.

Hon. James Wilson,
Secretary of Agriculture.

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FORESTATION OF THE SAND HILLS OF NEBRASKA AND KANSAS.

PURPOSE OF THE BULLETIN.

Not only has the tree planting by the Forest Service in the Nebraska sand hills aroused a wide interest, but at present, under the provisions of the act of March 4, 1911, which permits the free distribution of trees within the area covered by the Kinkaid Homestead Act, there is within that region a decided increase in tree planting. Because of this impetus to tree growing, it is worth while to give a record of the work which has been accomplished and to show for the benefit of planters the mistakes which have been made and the successes which have been attained.

The problem of foresting the sand hills is unique. It is not so difficult as some similar undertakings, and those who have followed the work closely have never had any doubt as to its ultimate success.

Both in Europe,[1] in the Netherlands, Gascony, Prussia, and Denmark, and in this country, at Cape Cod, the fixation of coastal sand dunes has been accomplished, even where the sand had been constantly moving and where forest trees were introduced successfully only after grasses and other low plants had been used to bind the soil. In all of these regions the ultimate object has been the permanent fixation by means of forests, and except in immediate proximity to the sea, where wind and salt spray have made tree growth impossible, this object has usually been accomplished.

Afforestation of interior, or continental dunes, however, is a different problem from afforestation of coastal dunes. It has been accomplished most notably in Turkestan, where the dune region closely resembles the sand hills of Nebraska. The coastal regions have one advantage over interior sand hills in the greater moisture content of both soil and atmosphere, and this gives an opportunity to choose from a greater variety of suitable trees. On the other hand, the sand-hill regions of Kansas and Nebraska have very little shifting sand; the necessity for planting preliminary soil binders never arises, since native vegetation quickly takes possession of new dune formations if left alone. In fact it is sometimes thought that there is enough vegetation to present an obstacle to the forester. This difficulty is

[1] Methods Used for Controlling and Reclaiming Sand Dunes, Bulletin 57, Bureau of Plant Industry, U. S. Dept. of Agriculture, 1904.

so easily overcome, however, that there is no real obstacle to forestation except fire. The damage through fire depends very largely on public sentiment; since sentiment has elsewhere been educated to consider fire a common enemy, it seems probable that the grass fires of the sand hills will cease to be treated as matters of no moment and will come to an end as they have in the prairies farther east. With the prairie fire controlled, forests may easily be grown in the sand hills.

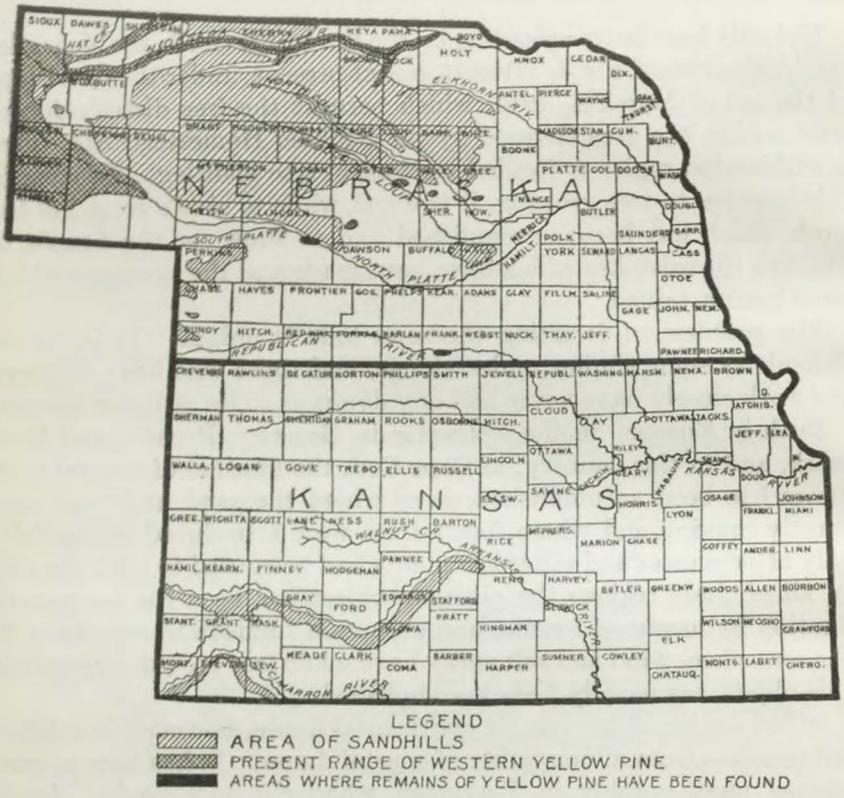

FIG. 1.—The sand-hill regions of Nebraska and Kansas.

THE SAND-HILL REGION.

LOCATION AND AREA.

The sand hills of Nebraska are mainly in the northwestern third of the State; they occupy an area of approximately 20,000 square miles north of the Platte River and west of the middle line of Holt and Greeley Counties. Hall, Perkins, Chase, and Dundy Counties also contain sand-hill areas. (See Fig. 1.) Of the entire area of 76,840 square miles within the State they occupy approximately one-fourth. The line between sand hills and sandy ground of the Pine Ridge,

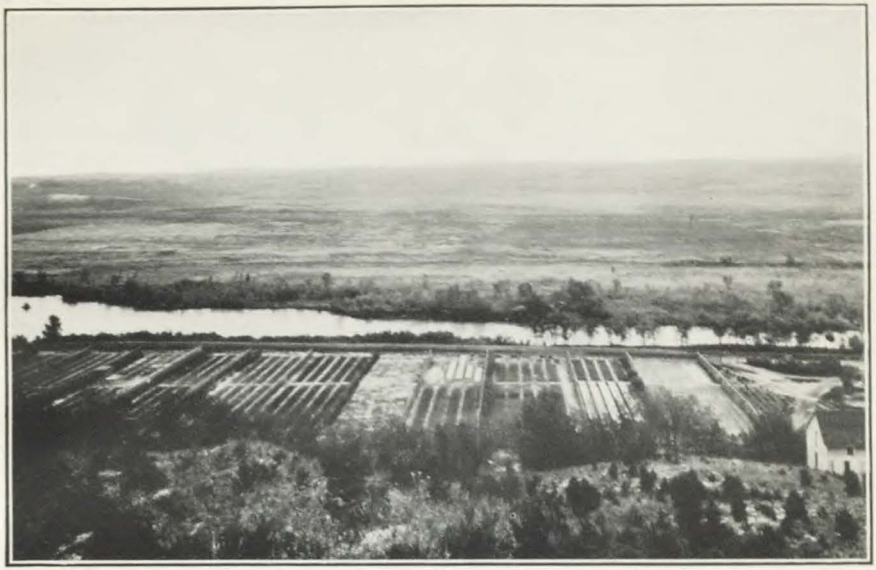

FIG. 1.—THE HALSEY NURSERY, AND A GENERAL VIEW OF THE SAND HILLS NORTH OF THE MIDDLE LOUP RIVER AT HALSEY, NEBR.

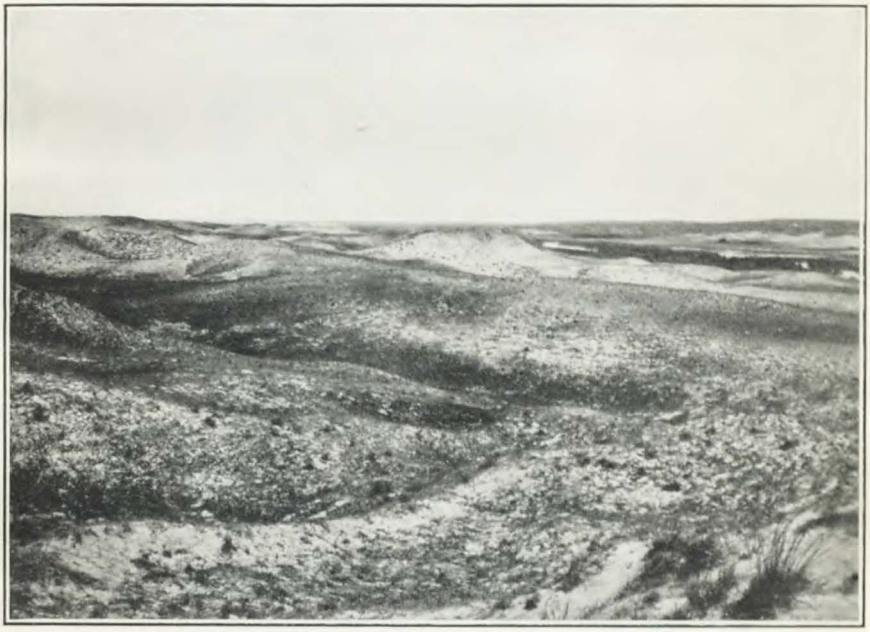

FIG. 2.—A GENERAL VIEW OF THE SAND HILLS SOUTH OF THE MIDDLE LOUP RIVER, IN THE LOUP DIVISION OF THE NEBRASKA NATIONAL FOREST.

Hills overgrazed and especially fitted for forestry.

which occupies the northwest corner of the State, is not clearly defined, since the Arikaree formation, which is the foundation of the Pine Ridge, outcrops within the sand-hill area, notably along the Niobrara, Snake, and north side of the Platte Rivers. The absolute elevation of the sand hills is 1,900 feet at the east and 3,900 feet at the west end. Their elevation, however, is not appreciably greater than that of the surrounding land of other formations.

The Kansas sand hills are much less extensive. They occupy a strip of ground from 5 to 30 miles wide on the south side of the Arkansas River, from the west boundary of the State eastward to the vicinity of Great Bend and Hutchinson. At the eastern extremity, however, these hills are not strictly dunes, but are agricultural in character, and hence hardly come within the category of true sand hills. A second strip of sand hills is found south of the Cimarron River, in southwestern Kansas, and is even less extensive than the first. The total area of sand hills in Kansas is about 1,500 square miles, or not more than one-fiftieth of the area of the State. Their elevation increases from east to west and is from 2,500 to 3,500 feet.

Of the entire area of Kansas and Nebraska it is safe to say that fully 15,000 square miles, or nearly 10 per cent, are sand hills not fitted for agriculture, and therefore of greatest value as forest lands. These areas lie in the semiarid belt, mainly west of the one hundredth meridian, where the rainfall is generally less than 22 inches per annum.

ORIGIN AND STRUCTURE.

The Nebraska sand hills have undoubtedly been formed [1] by the breaking down of the Arikaree, a Tertiary sandstone which still exists in the Pine Ridge and in various "toadstool parks" in the western and northwestern counties, and which outcrops along the Niobrara, Snake, and North Platte Rivers. The sand has been moved to the eastward by the action of wind and water, principally the former, forming a layer from a few feet to several hundred feet thick above the Pierre shale which underlies the entire region. This action has been very recent, in fact, has hardly yet ceased, and to some extent, as in Custer County, the sand has covered the loess, or heavy clay-loam soil, which is also a recent formation. There is little evidence of the direct action of water in bringing this sand eastward. Probably the Niobrara has had a very potent influence in its immediate vicinity, but most of the sand must have been carried from this stream to the southeast by wind, or to the eastward by some large stream which does not now exist, in the southern part of the region.

The Kansas sand hills have been similarly formed, but with material of different origin. Those near the Arkansas River,[2] and probably

[1] Nebraska Geological Survey, Report of the State Geologist, 1903, vol. 1.

[2] Soil Survey of the Garden City Area, Bureau of Soils, U. S. Dept. of Agriculture, 1904.

those along the Cimarron also, have been formed by the breaking down of the Tertiary grit found in the immediate vicinity, and also by the weathering of the rocks on the mountain sides at the headwaters of the Arkansas River. The mineral composition of these dune sands shows them to be composed of quartz, feldspar, mica, iron oxide, and other constituents which are characteristic of the local grit and of the granites of the Rocky Mountains. While these sand dunes are composed [1] of almost pure sand, medium or fine, and with particles more or less rounded, there are present certain constituents which are not found in the Nebraska sands and which give the particles greater cohesion. The most important of these is probably iron oxide. The Colorado sand, which is found in a few localities in the Kansas sand hills, is very little different from the dune sand either chemically or minerally, but it has a slightly larger percentage of very fine sand and silt, and hence coheres more strongly.

While the Kansas sand hills are, because of the greater amount of silt, compact and now almost perfectly stable, the Nebraska sand hills are still being moved, in many instances by the wind. Like all "active" sand dunes, they have a rough topography, whereas the Kansas hills are low, and the topography of that region may be typified by the word "rolling."

The Nebraska sand hills may be divided into three regions, to be called the "wet-valley region," the "dry-valley region," and the "choppy hill region." The wet-valley region is, generally speaking, the northern portion of the hills and is typified by long valleys with an easterly and westerly bearing, in the east end of which there are usually one or two small bodies of water. These bodies of water vary greatly in size from year to year. The valleys are sometimes valuable for agriculture, and, especially in the vicinity of the lakes, make excellent hay meadows.

The dry-valley region occupies the southern half of the sand-hill region and differs from the wet-valley region mainly in having a better soil drainage, which prevents the formation of lakes and ponds. The topography is more rugged, and the hills are higher.

At various places within both the wet and dry valley regions there are found areas of choppy hills, one of the largest of such areas being that lying between the Middle Loup and Dismal Rivers. While the general trend of the ridges and valleys in these localities is west-northwest and east-southeast, as throughout the region, here the ridges are short and frequently broken by round-topped hills, while the valleys are seldom more than a quarter of a mile long and are more frequently merely pockets. The underground drainage is com-

[1] Six miles south of Garden City dune sand was found to be made up in the following proportions: Grave 1.1 per cent, coarse sand 8 per cent, medium sand 12.2 per cent, fine sand 56.2 per cent, very fine sand 16.6 per cent, silt 1 per cent, clay 4.6 per cent.

plete, and there is no surface run-off. The hills are comparatively high and rise from 60 to 100 feet above the interior valleys and from 200 to 300 feet above the valleys of the main streams, such as the Middle Loup. Along such streams permanent springs are more or less common, which indicates that an impervious substratum underlies the hills at no great depth. It is with these choppy hills that the forester is principally concerned, since they have no agricultural value whatever. They are evidently the youngest of the hills and have not yet ceased to be affected by the wind, though there is evidence that they have become a good deal more stable since the buffalo ceased to trample them. With overgrazing or any other influence which kills the vegetation the sand is released, "blow-outs" are formed, and in a few years a hilltop may change position appreciably. Since these least stable hills are so near to the agricultural land of eastern Nebraska their fixation is of great importance.

While the dune sand of the hilltops, as shown by analysis of the soil at Halsey, is practically pure silica [1] and contains less than 1 per cent of organic matter, the soil of the valleys and pockets is usually very rich in humus. The continuous collection of this material is made possible by the lack of surface drainage. As a result of it the vegetation of the bottoms is very heavy, while that of the hilltops is correspondingly light. The heavy vegetation of the bottoms uses up a lot of the moisture, and this, in the absence of rains, makes these by all odds the most difficult sites for the introduction of new plant life.

CLIMATE.

PRECIPITATION.

The rainfall of the sand-hill region varies from 15 to 26 inches per annum. It is well distributed to assist the ordinary forms of vegetation, since it comes largely in the growing season, but because of the decided lack of snow young woody plants which need protection in their first years have great difficulty in getting started.

The precipitation increases month by month from the beginning to the middle of the year and then decreases to the end of the year. Since May and June are moist, coniferous-tree growth seems to be especially favored. The dryness of the fall months permits proper ripening of woody growth, so that fall frosts seldom do any harm.

Table 1 shows the precipitation at Halsey, Nebr., and Garden City, Kans., headquarters of the Nebraska and Kansas Forests, respectively. For comparison with a yellow-pine region the records for Fort Robinson, Nebr., are also given.

[1] Analysis of soil from hilltop at Halsey Nursery showed 97.4 per cent of insoluble mineral matter.

TABLE 1.—*Precipitation by months, Halsey, Nebr., and Garden City, Kans.*[1]

Month.	Halsey, Nebr.[2]			Garden City, Kans.[3]			Fort Robinson, Nebr.
	Lowest record.	Highest record.	Normal.	Lowest record.	Highest record.	Normal.	Normal.
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
January	0.08	0.68	0.40	Trace.	1.55	0.32	0.66
February	Trace.	1.04	.45	Trace.	4.55	.82	.57
March	.16	3.32	.96	Trace.	2.46	.84	1.16
April	.13	6.37	2.54	.06	5.70	2.06	1.65
May	2.17	6.53	4.18	.42	6.49	2.34	2.69
June	.79	5.64	3.55	.60	7.89	3.51	2.91
July	1.63	5.28	3.79	.62	7.91	3.25	2.04
August	.82	5.84	2.68	.15	4.24	1.79	1.57
September	.30	4.62	1.75	.03	4.57	1.78	1.08
October	Trace.	4.81	1.46	Trace.	3.78	1.08	1.32
November	.05	1.19	.45	Trace.	3.77	.64	.39
December	Trace.	1.78	.75	Trace.	2.00	.62	.69
Year	17.71	28.44	22.96	8.92	28.75	19.05	16.73

[1] Data furnished by local offices Weather Bureau, Lincoln and Topeka.
[2] Record nine years, 1903–1911.
[3] Record 22½ years, 1889–1911.

Both in Kansas and Nebraska the precipitation increases rapidly from west to east, which is contrary to the usual rule of greater precipitation with greater elevation. Table 2 shows this for a number of stations in or adjacent to the sand-hill regions.

TABLE 2.—*Annual precipitation*[4] *of sand-hill region.*

Station.	Longitude.	Mean annual precipitation.	Length of record.
NEBRASKA.	° ′	*Inches.*	*Years.*
Ewing	98 20	23.01	21
Valentine	100 30	22.46	23
North Platte	100 45	18.86	38
Bridgeport	103 05	15.44	15
KANSAS.			
Hutchinson	98 00	28.44	12
Dodge	100 00	20.84	33
Ulysses	101 20	17.24	18
Coolidge	102 00	15.51	12

[4] Data from Climatological Reports, Nebraska and Kansas Sections Weather Bureau, 1911.

While the precipitation in Kansas is just about equal to that of points in Nebraska corresponding in longitude, it is important to remember that the same amount is less effective in Kansas because of the much higher rate of evaporation. The evaporation at Dodge, Kans., for example, was 54.6 inches per annum, while for the same period at North Platte, Nebr., it was only 41.3 inches per annum.

While the precipitation in none of the sand-hill regions is great, and varies much from year to year as well as from month to month, the lowest quantity ever recorded at Dodge, Kans.,[5] 10.1 inches in

[5] During a period of 33 years in which the drought period of the nineties is included.

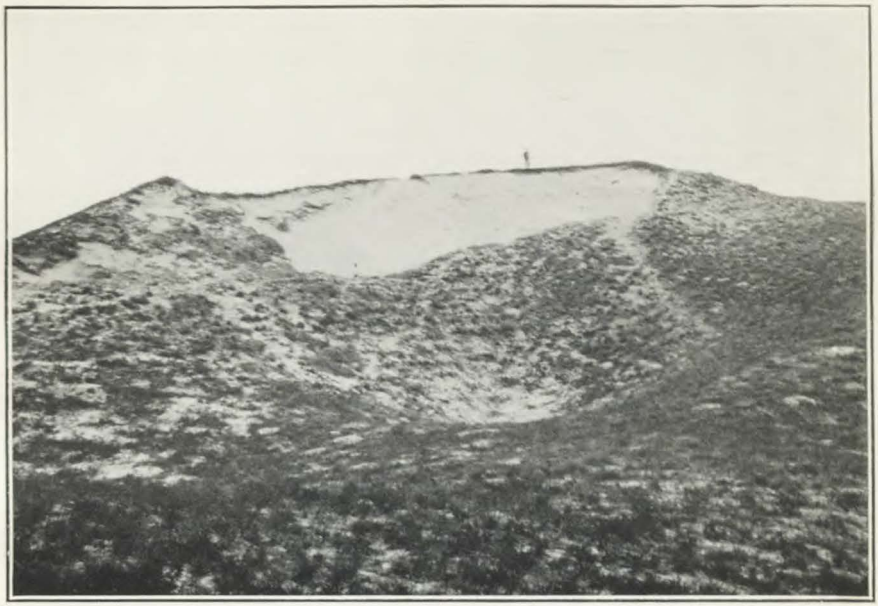

FIG. 1.—A "BLOW-OUT" IN THE NORTHWEST FACE OF A HILL.

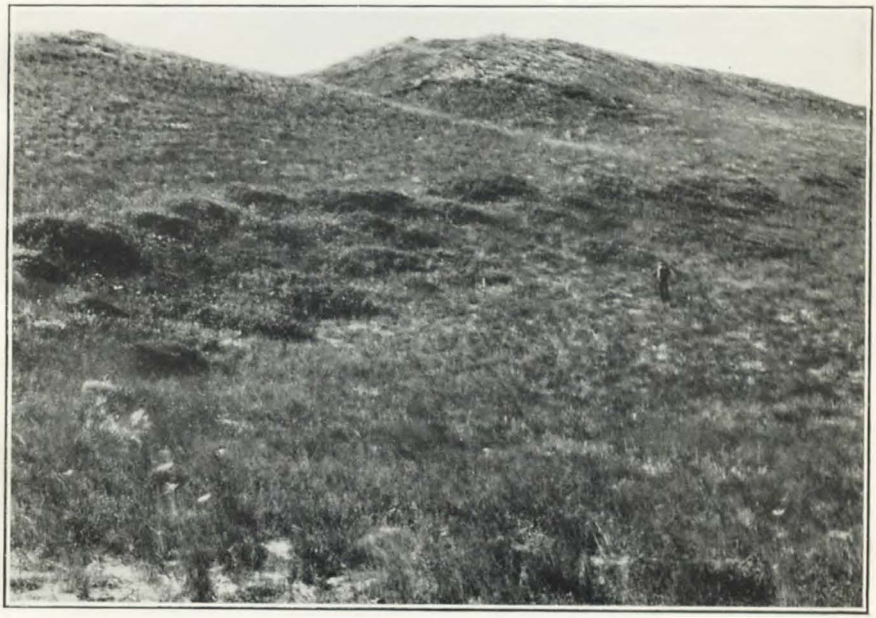

FIG. 2.—SAND-HILL WILLOWS ON MOIST NORTH SLOPES WHERE PLANTING IS MOST SUCCESSFUL AND EVEN DIRECT SEEDING IS POSSIBLE.

one year, would, if applied to the receptive soil of the sand hills, undoubtedly be sufficient to sustain tree growth, if the trees were already well established. Only newly planted trees are likely to suffer. It is surprising how well the sand below the surface layer will hold water and how readily moisture is brought up from the lower depths by capillary action. While the quantity is less than in a heavy soil, it varies less from season to season. In the fall of 1911, after unusual drought for several months at Garden City, the very sandy soil of the hilltops was found to be dry to a depth of only 8 inches, while in some places the more compact soils were dry to a depth of 34 inches. In the Nebraska sand hills in 1911 the sand dried out to a depth of about 4 inches where there was no vegetation, but to a depth of from 14 to 18 inches under sod. Under these circumstances trees of the previous year's planting suffered very little.

TEMPERATURE.

Table 3 shows the important features with respect to the temperature at Halsey and Garden City. The mean temperatures at Fort Robinson are also given.

TABLE 3.—*Monthly temperatures at Halsey, Nebr., and at Garden City, Kans.*[1]

Month.	Mean temperature.			Mean maximum temperature.[2]		Mean minimum temperature.[3]	
	Fort Robinson.	Halsey.	Garden City.	Halsey.	Garden City.	Halsey.	Garden City.
	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*
January	23.4	23.0	30.6	36.2	46	9.9	17
February	23.2	26.8	29.2	41.0	43	12.7	15
March	34.1	38.6	43.3	53.6	59	23.7	26
April	46.4	48.6	54.6	64.4	72	32.7	38
May	55.1	57.6	63.4	72.1	80	43.0	49
June	65.3	68.0	73.2	81.8	88	54.1	59
July	71.0	72.5	77.4	86.8	92	58.2	63
August	70.1	72.6	76.5	87.6	93	57.7	63
September	60.9	65.0	69.4	81.1	84	48.8	54
October	48.1	51.1	55.6	67.5	73	34.7	39
November	35.0	38.2	43.0	52.3	60	24.1	26
December	27.4	27.5	31.6	40.0	46	15.0	17
Year	46.7	49.1	54.0	63.7	69.5	34.6	38.8

[1] From data furnished by local Weather Bureau offices at Lincoln and Topeka.
[2] Absolute maximum: Halsey, 107°; Garden City, 112°.
[3] Absolute minimum: Halsey, —32°; Garden City, —32°.

NOTE.—Length of the growing season (data from Weather Bureau Bulletin "Q"): Halsey, 132 days; Garden City, 155 days.

HUMIDITY.

The atmospheric humidity of the sand-hill region is rather low as compared with the East, but considerably higher than that of the Rocky Mountain region, where coniferous forests grow naturally. It can not, therefore, be said that the lack of atmospheric moisture explains the lack of forests in the sand hills. The mean annual humidity in the vicinity of Halsey is about 67 per cent and in the

vicinity of Garden City about 65 per cent. While for short periods the humidity may be low, the variation by months is slight. January and February have the highest relative humidity.

WIND.

Both regions are decidedly windy, but the Kansas region has a mean wind velocity 8 per cent greater than the Nebraska region. While the south winds of summer are fairly desiccating, it has been shown at Halsey that the summer winds have very little damaging effect, unless the soil is extremely dry. The early spring winds from the northwest are damaging to both field and nursery, because they move the sand and dry out the plants. The winter winds, while not so high, dry out the plants because of the lack of protective snow covering. Trees which are well established do not suffer as much as those newly planted; fall planting, therefore, is almost certain to result in heavy losses or complete failure.

Table 4 shows the velocity and direction of the wind at Valentine, Nebr., and Dodge, Kans., the stations where such records are obtainable near the sand-hill planting areas.

TABLE 4.—*Direction and velocity of wind, by months.*

Month.	Valentine, Nebr.		Dodge City, Kans.	
	Prevailing direction.[1]	Velocity per hour.[2]	Prevailing direction.[2]	Velocity per hour.[2]
		Miles.		*Miles.*
January	NW.	9.8	NW.	10.1
February	NW.	10.0	NW.	10.9
March	N.	11.7	NW.	12.7
April	N.	13.0	SE.	13.8
May	N.	12.0	SE.	13.2
June	S.	11.1	SE.	12.7
July	S.	10.0	SE.	11.3
August	S.	9.6	SE.	10.6
September	S.	10.5	SE.	11.2
October	NW.	10.5	SE.	11.0
November	NW.	10.0	NW.	9.9
December	NW.	9.8	NW.	10.1
Year	.....	10.7	.....	11.5

[1] Data from Weather Bureau Bulletin "Q."
[2] Data from local offices Weather Bureau, Lincoln and Topeka.

THE IMPORTANT CLIMATIC FEATURES.

The three most important features of the climates of both sand-hill regions are: (1) The lack of winter precipitation in the form of snow, to form a protective covering for young trees; (2) the great variations in precipitation from month to month, partly counterbalanced by the good water-storing properties of the hills; and (3) the winds of late winter and early spring. While the temperature extremes are not great, the Kansas region doubtless suffers most by reason of its constantly higher temperatures. Especially in summer

these hasten the depletion of the soil moisture and, if young trees become covered with sand, cause them to be parched to crispness.

Temperatures are higher at Halsey and Garden City than at Fort Robinson, Nebr., in the heart of the yellow-pine belt of northwestern Nebraska, where precipitation is proportionately less.

VEGETATION.

The sand hills of Nebraska and Kansas produce a great variety of grasses, herbs, and shrubs, and a few trees.

GRASSES.

The distinctive vegetation of the sand hills, as of most semiarid regions, consists of grasses. The most common and most widely distributed grass is the sand-hill bunch grass (*Andropogon scoparius*), which indicates a stable soil. The grasses which first come in on loose sand, and which are typical of "blow-outs" and south slopes, are the long-leafed reed grass (*Calamovilfa longifolia*), which is sometimes 4 or 5 feet high, but forms a very light cover, the redfieldia (*Redfieldia flexuosa*), the eragrostis (*Eragrostis tenuis*), and the prairie muhlenbergia (*Muhlenbergia pungens*). No less distinct is the switch grass (*Panicum virgatum*), which forms dense tangles in the rich soil of the dry-bottom situations and is frequently cut for hay. Only in the areas of harder ground, which occur throughout the sand hills, are the grama and buffalo grasses common; these are the most valuable of all the grasses for both summer and winter forage.

HERBACEOUS PLANTS.

Some of the most common herbaceous plants are the digitate psoralea (*Psoralea digitata*), the prairie thistle (*Carduus plattensis*), a broad-leafed cactus (*Opuntia polycantha*), several species of *Euphorbia* (spurges, locally called "milkweed"), and the wild sweet pea (*Lathyrus ornatus*). Of common weeds the sunflower and the squirrel-tail or tickle grass are the most widely distributed and the most persistent. Russian thistle gains a foothold in the Kansas sand hills wherever sod is broken.

SHRUBS.

Of the numerous woody undershrubs the yucca, or soap-weed (*Yucca glauca*), is probably the most striking plant of the sand-hill region and is least abundant where the soil is the most stable and firm. Other shrubs, most of which are more or less gregarious and form clumps or mats on the ground, are the sand-hill willow (*Salix humilis*), very common on north slopes and indicative of good moisture conditions,[1] the redroot or New Jersey tea (*Ceanothus ovatus*),

[1] Even the sand-bar and the peach-leafed willows have been found with this smaller species, where the moisture conditions are especially good.

typical of sandy hilltops; the sand cherry (*Prunus besseyi*), found in almost any site, but especially in the loose sand around blow-outs; and the shoe-string bush (*Amorpha canescens*). Wolfberry (*Symphoricarpos occidentalis*), chokecherry, and wild plum frequently form thickets on the slopes of pockets facing the southeast, where they are favored by the moisture from snowdrifts. The first named seldom becomes more than 2½ feet high, the other two frequently 15 feet.

From the standpoint of forestry one of the most important of the woody plants is the low bearberry or kinnikinnik (*Arctostaphylos uva-ursi*). While this grows in only a few limited localities, on moist north slopes, it is thought to be indicative of conditions favorable for western yellow pine, since it is an almost invariable associate of that tree in the Rocky Mountains.

Typical of the stream valleys in both Kansas and Nebraska are the false indigo (*Amorpha fruticosa*), the buffalo berry, peach-leafed willow, sand-bar willow, wolfberry, plum, and chokecherry. The diamond willow, one of the Nebraska sand hills' most valuable small trees, is not found in Kansas. On the whole, shrubby growth is much more typical of the Nebraska than the Kansas sand hills, which usually have a heavy grass sod that does not permit the growth of shrubs.

TREES.

In only a few localities in the Nebraska sand hills do actual trees grow; in the Kansas region they are still more rare. Of the hardwoods, green ash, hackberry, cottonwood, and aspen are the only ones which attain to tree size in the sand hills proper. While these species (except aspen) grow, for the most part, along the main watercourses, there are clumps of them in the sand hills proper. All of the trees so far found are less than 25 years old and have sprung from sprouts after the last general prairie fire, so that it is impossible to say what size the trees may attain at maturity. The largest are now no more than 25 feet high and 8 inches in diameter. Probably in the poor soil they will never attain large size.

Western yellow pine, on the contrary, grows as large in the vicinity of the sand hills as elsewhere in its range. Practically, there is no yellow pine in the sand hills proper, it being confined to the Arikaree formation on the west, north, and south sides of the sand hills and to the loess soil of one or two canyons on the east. Under favorable moisture conditions in the Arikaree formation of the Pine Ridge yellow pine not infrequently reaches a height of 100 feet. There are also many fine specimens in this formation along the Niobrara and Snake Rivers and in the counties west of the sand hills. In considering the possibility of growing yellow pine in the sand hills the fact

FIG. 1.—A SMALL GROVE OF HACKBERRY, IN THE SAND HILLS 4 MILES FROM NEAREST STREAM.

Maximum height 25 feet, diameter 8 inches.

FIG. 2.—YOUNG NATIVE WESTERN YELLOW PINE IN THE NEBRASKA SAND-HILL REGION NEAR THE NIOBRARA RIVER, NEBRASKA NATIONAL FOREST.

should not be lost sight of that the sand hills contain the same material as the sandstone of the Arikaree formation.

Writing on information obtained in 1893, Rydberg [1] stated:

> Pine logs have at a few places been found buried in the sand. There is a canyon in Custer County which still contains living pines. It is very hard to explain how pine seed could have been carried from the Pine Ridge in Dawes and Sheridan Counties to Custer County, and none have been sown in the intermediate tract. * * * Very likely in former days the pines grew, if not all over the hills, at least in many places among them. The red cedar is at present not uncommon on the hillside along the Dismal River, and I myself found stumps and fragments of this tree at several places in the sand hills, where there was no vestige of living trees.

It seems very likely that yellow pine was formerly common in all of the sand-hill region of Nebraska, as well as in the sandstone country; that it has been driven out of the sand-hill, or "long-grass," region by the repeated destructive fires of the past; and that it has been able to survive in practically all of the "short-grass" sandstone region, because the fires there were much less destructive. It is a well-known fact that yellow pine is not killed by light grass fires. The same conditions have probably largely determined the present distribution of red cedar. It is found now in Nebraska sand hills, mainly on the hard short-grass ground along the Dismal River, though it is well known that it will grow in sand; and in Kansas it is, similarly, found only on the hard ground southwest of the Kansas Forest.

To sum up the situation as to tree growth in the Nebraska sand hills it may be said that, while unfavorable natural conditions, assisted by fires, have prevented the natural growth of coniferous forests, the soil conditions are favorable for the growth of the pines, and the climatic conditions are not such as to prevent the successful growing of these species by artificial means. The Kansas sand hills, on the other hand, do not show any evidence of ever having supported pine forests, probably on account of their recent formation, their great distance from the nearest established forests, and the distinct lack of snow, which is essential to natural reproduction. But there is nothing in these facts to prevent the growth of forests in the Kansas hills.

INDUSTRIES.

The principal industry of the sand-hill region of both States is cattle raising. The sand hills furnish excellent summer feed,[2] which, during the spring and summer, is succulent and productive of both beef and milk, but after freezing is much less valuable than the forage of the short-grass region. The hay makes good roughage, but lacks protein, and is not strengthening if fed without grain. Occasionally cattle

[1] Flora of the Sand Hills of Nebraska, Bulletin of the Division of Botany, Vol. III, no. 3, 1895.

[2] Forage Crops for the Sand-Hill Section of Nebraska, Cir. 80, Bureau of Plant Industry, U. S. Dept. of Agriculture.

may be wintered in the hills. To be profitable the industry is dependent upon a supply of hay in connection with each summer range, except when steers are imported and grazed for the summer season only. For summer range alone from 10 to 25 acres are required to the head. The hills which are valuable only for this purpose, therefore, do not produce a revenue to the stockman of more than 50 cents per acre, and the revenue to the Government for grazing use of National Forest land is only about one-tenth of this, or sometimes not more than 2 cents per acre.

The development of water is necessary to the proper use of the sand hills for grazing, since there is no surface water, except in the wet valleys, and at times even this can not be reached by cattle without danger. Much of the sand-hill range would be more productive if more windmills were used, since cattle seldom use the grass more than 2 or 3 miles from water, and the ground near the water is therefore severely overgrazed, while good feed farther away goes to waste. In the wet valleys water is usually obtained at from 30 to 40 feet, and seldom in the driest situations at more than 125 feet. For pumping, windmills prevail, since they will operate for weeks without attention.

The lower ground capable of producing natural or introduced hay crops has the highest value. It produces from 1 to 2 tons per acre, valued at from $3 to $5 per ton. Only a very small proportion of the sand-hill region, or that lying along the larger streams in some of the wide interior valleys, and the "hard ground" which occurs in small areas throughout, is fitted for agriculture. Potatoes and corn are the principal crops, though the nights are too cool for the best growth of corn. Much of the land which in past years has been considered agricultural has had to be abandoned because of the rapid impoverishment of the light soil and because of its movement by the mechanical action of the wind after the sod is destroyed by cultivation. On the other hand, much of this land has been profitably handled for forage crops such as alfalfa, and for such crops it is well fitted.[1]

Since the sand hills proper produce such a small revenue, and since either excessive grazing or agriculture may quickly destroy the productiveness of the land, the advantage of using the sand hills for the production of timber may readily be seen. Until the planting work has advanced much farther, however, and the rate of growth of the trees has been determined, it can not be stated with safety that forestry will bring a higher return on the land than conservative grazing. It is, however, quite certain that forestry will in time make possible much more extensive agriculture, both by protecting from wind and by changing the character of the soil by the addition of

[1] Forage Crops of the Sand-Hill Section of Nebraska, Circular 80, Bureau of Plant Industry, U. S. Dept. of Agriculture.

humus so that it will not blow.[1] This is especially true of the low rolling hills of the Platte region of Nebraska and of the Kansas hills. Much of the sand-hill ground is too precipitous for agriculture.

NEED FOR FORESTS IN THE SAND-HILL REGION.

Nebraska and Kansas have about as small a proportion of forest area as any two States in the Union. The natural forests are confined to belts of hardwoods along the eastern borders of these two States and to the pine forests of northwestern Nebraska. The States produce practically no softwood lumber. While under present conditions lumber is imported from the Northwest more cheaply than it could possibly be grown in these States, the cheap supply of that region will ultimately be exhausted. With the depletion of the natural timber supplies in the Lake States and the Northwest, the prairie States will eventually have great difficulty in obtaining lumber. Therefore a supply of lumber for the future is one object of forest planting in the sand hills.

A more important consideration, however, is the question of a local timber supply in connection with the stock-raising and agricultural industries of the sand-hill regions themselves. A large part of the demand from ranches is for fence posts and unsawed timber for other improvements. Since the native cedar has been largely exhausted it has been necessary to purchase timber at disproportionately high rates.

While it can not be said that forests are needed in the sand-hill regions to conserve water, since the hills themselves are perfect reservoirs and the streams all drain to the east, where water for irrigation is not at present needed, still the planting of forests in the sand hills will check the wind locally and generally it will prevent the further encroachment of the sand dunes on the fertile land to the east and will ameliorate the dryness of the atmosphere so that the agricultural land to the east may receive a greater amount of precipitation. Of these influences the local effects of groves of trees acting as windbreaks will be felt first, and for this reason the planting of trees by local residents after the Government has thoroughly experimented with species and methods should be strongly encouraged. Forests should not only help to make tillable those soils which are already fertile by reducing the exposure to wind, but planted extensively on poor soils, they should ultimately make them fertile enough and should so change the physical composition of the soil that they may be tilled with safety.

Extensive forests on rough land are for timber and for general climatic effect. The less extensive, which will be planted on rolling land, are directly to benefit agriculture through their local effects on wind and soil.

[1] The Control of Blowing Soils, Farmers' Bulletin 421, U. S. Dept. of Agriculture.

BEGINNINGS OF FOREST PLANTING IN THE SAND-HILL REGION.

It is thought that the first suggestion that the Federal Government should plant forests in the sand hills of Nebraska came from Dr. Charles E. Bessey, of the University of Nebraska, about 1890. Before this time settlers had made plantings in the sand hills, as throughout Nebraska and the other Middle Western States, under the timber-culture act (1878–1891). This planting did little to justify the purpose of the act, which was to stimulate the cultivation of timber in the treeless region, and almost without exception the plantations of hardwood trees failed because of drought, light soil, and lack of protection from cattle. About the only successful plantations were those made with cottonwood in the low, moist swales where farmsteads were established. Some of these plantations have attained good size and the trees have been of inestimable benefit in protecting the ranch buildings. In many cases these groves of cottonwood have furnished the only shelter for herds of cattle in the most severe winters.

In 1891 the Federal Division of Forestry adopted Dr. Bessey's suggestion and established a small plantation of jack and Norway pines on the ranch of the Bruner brothers, in Holt County, 4 miles west of Swan, Nebr., with trees collected in the woods of Wisconsin. Other species used to a limited extent were Scotch, Austrian, and western yellow pines, Douglas fir, and arbor vitæ. The yellow pine was obtained from a commercial nursery. These species were mostly used in such small numbers as to make no showing, and the only species that are at present worth considering in the plantation are the jack, western yellow, and Scotch pines. Of all the others less than 3 per cent survive.

Most of the trees used in this plantation were about 3 years old and 8 inches in height. Reports made on the plantation in 1896 and 1903, which show the survival and condition of the trees of the three successful species, are summarized in Tables 5 and 6.

TABLE 5.—*Number of trees planted on Bruner brothers' ranch, in Holt County, Nebr., and number that survived.*[1]

Species.	Condition at time of planting.	Number planted.	Oct. 1, 1896, trees living.		Dec. 1, 1903, trees living.	
			Number.	Per cent.	Number.	Per cent.
Jack pine	Fair	2,362	2,055	87	1,729	73
Scotch pine	Poor to fair	1,350	.....	.....	484	35
Yellow pine	Good	305	[2] 139	45	141	46

[1] From paper by Charles A. Scott, Nebraska Forestry and Park Association, January, 1904.
[2] A few trees were probably overlooked, since later counts show a larger number alive.

FIG. 1.—JACK PINE ON THE BRUNER PLANTATION 17 YEARS AFTER PLANTING, HOLT COUNTY, NEBR.

FIG. 2.—THE FIRST PLANTING OF JACK PINE AT HALSEY WHEN THE PLANTATION WAS 4 YEARS OLD; NORTHEAST SLOPE FACING MIDDLE LOUP RIVER.

FIG. 1.—THE FIRST PLANTING OF JACK PINE AT HALSEY, NEBR., AT THE AGE OF 8 YEARS.

Note how the trees have closed together since the fourth year. (See Pl. V, fig. 2.)

FIG 2.—A FINE INDIVIDUAL SPECIMEN OF YELLOW PINE, PLANTED IN 1904, WHICH IN ITS EIGHTH YEAR MADE A GROWTH OF 12 INCHES.

Total height 5 feet 8 inches.

TABLE 6.—*Relative rate of growth of the three species of pines on Bruner Bros.' ranch up to 1903.*[1]

	Tallest height class.	Middle height class.	Shortest height class.
Average height, all species	19.4 feet	15.9 feet	
Average diameter, all species	3 inches	2.1 inches	Less than 1 inch.
	Number.	*Number.*	*Number.*
Jack pines	614	806	309
Scotch pines	12	96	376
Western yellow pines	0	21	120

[1] From paper by Charles A. Scott, Nebraska Forestry and Park Association, January, 1904.

From Tables 5 and 6 it is apparent that jack pine has far outstripped the other species in the percentage of survival and that it has made much better height growth, there being a relatively small proportion of the Scotch pine in the tallest class, and no yellow pine. Yet it is also noteworthy that Scotch pine made good height growth and that there was no loss among the yellow pines between the years 1896 and 1903. In other words, once fairly established, yellow pine is quite certain to persist, and there can be little doubt but that, in the course of time, it will outstrip the jack pine, since the latter is a species which never attains a height of more than about 60 feet except in the very best soils which it occupies in the Lake States. Scotch pine also, if the proper variety is planted, is undoubtedly a good tree for sandy soils and for this climate.

The conditions in this miniature forest are entirely different from those in the surrounding hills, showing that the trees are permanently established. The grass has been killed out, the ground is covered with a light coat of needles, and, best of all, young seedlings of jack pine have appeared from time to time, from seed dropped by the planted trees. This is clear evidence of the adaptability of the species to the climate and soil of the region.

Another example of coniferous planting is the Charles Arter plantation of western yellow, or "bull" pine at Kirkwood, in the northern part of Rock County, Nebr. This plantation is just at the edge of the sand hills, and is not strictly in sand-hill soil, but rather in the heavier soil of the Arikaree formation as it appears on both sides of the lower Niobrara River. The plantation was made in the spring of 1893, with trees 12 to 20 inches high, obtained on the Niobrara River. The trees were planted 16 feet apart each way and were thoroughly cultivated for the first 10 years, after which care was taken to exclude stock and fire. The careful attention given this small grove doubtless explains in a large measure its phenomenal success. Very few of the trees died. In spite of the wide spacing of the trees the crowns now fully meet, and the trees have attained an average diameter at breast height of 9 inches.

The largest are about 12½, the smallest 6 inches in diameter. On a rough basis of calculation this plantation has had an increment of 85 cubic feet per acre per annum in the first 19 years of its existence. This represents remarkable productivity for a semiarid region.

NATIONAL FORESTS ESTABLISHED.

The success of this coniferous plantation of 1891 may be said to have formed the foundation for the establishment, in 1902, of the first National Forests, then known as forest reserves, in Nebraska. The Dismal River Reserve, lying between the Dismal and Middle Loup Rivers, comprised an area of 85,123 acres, and the Niobrara Reserve, lying between the Niobrara and Snake Rivers, comprised 123,779 acres. To these were added in 1906 the North Platte Reserve, lying some distance north of the North Platte River and bounded on the north by the line of the Chicago, Burlington & Quincy Railroad in the vicinity of Hyannis, Nebr. This area comprised 347,170 acres. The total area of about 556,000 acres, which was combined in 1908 into the Nebraska National Forest, covers less than 5 per cent of the Nebraska sand hills, a large portion of which are still in the public domain.

The similarity of the Nebraska and Kansas sand hills led to the belief that forests could be grown in the Kansas hills; there were, moreover, successful hardwood plantations there. One is immediately southwest of Garden City, where a plantation of black locust and cottonwood, made in 1894 and covering 10 acres, was partially cut in 1910, at the age of 16 years. The locust yielded a large number of 15 and 20 foot telephone poles, and posts at the rate of 3 per tree. The stumps are now producing vigorous sprouts, which in two years have attained a height of 14 feet and will soon produce a second crop.

With the idea that timber to supply local needs could be grown in the region the Garden City Forest Reserve was established in 1903, with an area of 97,280 acres. This was increased to 302,387 acres in 1908, when the name was changed to the Kansas National Forest. The area occupies a narrow strip of ground on the south side of the Arkansas River, from the west boundary of the State east to Garden City.

NURSERIES ESTABLISHED.

In the fall of 1902 the town of Halsey, Nebr., was selected as the headquarters of the Dismal River Reserve, and a small nursery was laid out beside the Middle Loup River, where the growing of jack and western yellow pine from seed was immediately begun. Since the spring of 1904, when the first seedlings became large enough for planting, this nursery has been increasing steadily in size and effi-

ciency, so that now the output is about 1,000,000 young trees a year. The trees have been very largely used in planting the hills immediately to the south of the nursery, but some have also been used on the North Platte division of the Forest. The work at this nursery is discussed elsewhere in this bulletin.

Similarly, after the Halsey nursery had become established, a small nursery was started at Garden City in 1907. Because it was intended to grow hardwood seedlings this nursery was laid out on the north side of the Arkansas River, where the soil is heavy and rich, and well adapted to that purpose. However, conifers have proved more desirable for the Kansas Forest, and various steps have been taken to prepare a soil suited to that class of stock; finally, in 1911, a small branch nursery was established on the south side of the Arkansas River, where the soil is sandy. The success of this nursery has not yet been thoroughly established.

In 1903 the area of the Halsey nursery was about one-half acre; in 1911 the combined areas of the Halsey and Garden City nurseries was more than 6 acres.

THE SAND-HILL NURSERIES.

The Halsey nursery was established in connection with the Nebraska planting work for the primary object of raising coniferous trees; that at Garden City was expected to produce mainly hardwood or broad-leafed trees for the Kansas planting. Hence, while the Garden City nursery has lately begun to produce conifers, it has not developed far in that direction, and it is probable that, with a new nursery in sandy soil, the nursery practice of the future will be much the same as at Halsey.

GARDEN CITY NURSERY.

The Garden City nursery was on the north side of the Arkansas River, about 2 miles west of Garden City, and on leased land, since there was nothing but very sandy land within the Forest on the south side of the river.

The situation is not more than 15 feet above the present river bed, and the soil is described as "Laurel loam," [1] a rather heavy, dark-brown loam, becoming lighter in color with depth. In some places the proportion of sand is rather large. The subsoil is much more sandy and gravelly than the topsoil. Pure sand is sometimes encountered at a depth of from 30 to 36 inches, and gravel nearly always at from 3 to 6 feet. The soil is made up of material deposited by inundations of the river and by silt and clay washed in from

[1] For this and subsequent data on the soil of the Garden City nursery, see Soil Survey of the Garden City Area, Bureau of Soils, U. S. Dept. of Agriculture, 1905.

the adjoining uplands.[1] It works rather stiff, is difficult to put in good tilth, and bakes after irrigating. Nevertheless, it is probably the richest soil in the entire Arkansas Valley.

In preparing this ground for the seed of hardwood trees, of which black and honey locusts, osage orange, ash, catalpa, walnut, and cottonwood have been the principal species, it is first plowed very deep and harrowed, then leveled, then marked for rows. Drills about 4 inches deep are then gouged out and run full of water, which is allowed to soak the soil for about one day before seed is sown. After the sowing the drill is filled with 1 to 2 inches of soil, depending on the size of the seed, and as soon as possible the soil is cultivated. One or more irrigations may be necessary before the seed germinates, but the soil is retentive of moisture if properly cultivated, and, usually, water has been applied only a few times during a season.

While the rows are 30 inches apart to permit the use of a 1-horse cultivator, there are from 1 to 15 trees per linear foot in the row. They develop very rapidly, and, in the fall of 1911, were mostly taken up, pruned, and heeled in for the 1912 planting. This practice permits the earliest possible planting when the ground thaws in the spring.

The size of seedlings of various species after one year, is as follows:

	Inches.		Inches.
Black locust	27	Osage orange	20
Honey locust	16	Catalpa	16
Green ash	7	Black walnut	10
Box elder	24		

Because the soil is so heavy it is necessary, in preparing for conifers, to introduce some sand and to raise the beds above the surrounding ground to facilitate drainage. At first, watering was done by sprinkling and surface irrigation, but in 1911 a system of subirrigation, using concrete tiles, was successfully introduced. A line of tile waters two lines of beds, each 4 feet wide. The water supply is obtained at no great depth and is pumped by windmill and gasoline engine into a storage basin.

It has also been necessary, in order to protect from birds and rodents, to use Pettis [2] frames very largely. These are simply wooden

[1] Mechanical analysis of soil of same character, obtained just east of Garden City, showed the following proportions of different-sized particles:

Stratum.	Fine gravel.	Coarse sand.	Medium sand.	Fine sand.	Very fine sand.	Silt.	Clay.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Soil	1.0	2.8	4.2	9.2	20.8	33.0	28.8
Subsoil	2.6	10.5	18.4	28.1	16.2	13.9	10.3

[2] See Forest Service Bulletin No. 76, "How to Grow and Plant Conifers in the Northeastern States," by C. R. Pettis.

frames, 18 inches high, which completely cover the seed beds, with the sides and tops covered with ¼-inch mesh wire netting.

Except for these three things—the use of sand, of raised beds, and of frames, the handling of coniferous stock is much the same as at the Halsey nursery.

HALSEY NURSERY.

LOCATION.

Although the Dismal River and Niobrara Forest Reserves were created at the same time, in 1902, the first named offered the greater inducement for planting, because of its nearness to the railroad and because of the poorer quality of its lands. The Niobrara reserve was 12 miles from the nearest railroad point. The Halsey nursery was established 2 miles west of Halsey, which is 48 miles northwest of Broken Bow and 200 miles from Lincoln. It was placed on the south side of the Middle Loup River, for protection from fire which might originate from locomotives. The Middle Loup is a large stream for the region and gives an abundant water supply at all seasons.

The nursery covers 5 acres on a second bench above the river at an elevation of 8 feet above the stream. The bench is 250 feet wide at this point, and at points above and below it is much wider.

The ground desired for nursery purposes, like most of the second bottom of the Loup, was covered with a dense but not continuous thicket of plum and cherry brush. Since it was necessary to have perfectly workable soil, this brush was cleared, and all roots were taken out, though at considerable expense.

SOIL AND MOISTURE.

The presence of the shrubby, humus-making cover had built up a good nursery soil. The bench had evidently been deposited by the river when it last changed its bed and consists of almost pure sand, with enough humus to make it dark gray in color to a depth of 10 to 20 inches. Below this depth it changes rapidly to a white, coarse sand with occasional gravel. Were it not for the nearness of the water table this soil would doubtless be quite arid, since the subsoil is too coarse to hold water or to transmit it readily to a dry surface. While deep-rooted plants can reach the water, this fact is of no value to tree seedlings, because the effort is made to curtail deep-root development in the nursery.

The problem of watering the nursery ground has never been difficult. At the outset sufficient water was easily pumped by a windmill for nursery as well as domestic use. It was stored in a cement-lined reservoir and distributed to the houses and to all parts of the nursery through 2-inch mains. Later, however, with a larger area under

cultivation and the need for irrigation clearly shown, it has been necessary to pump directly from the river. A 5-horsepower gasoline engine does the work, and most of the water is pumped direct into ditches, with only a small reserve supply for emergencies. This river water, especially in the spring when it carries considerable silt, as compared with clean well water, has a value in maintaining the fertility of the nursery soil. It is also warmer than the well water. With irrigating a great deal of leveling had to be done, and this, together with deep plowing, has in most places mixed the soil and subsoil to a depth of 20 or 30 inches.

While the need of watering depends on the weather, it is greatly increased by the extremely porous nature of the subsoil. Frequent applications are necessary, especially at midsummer and in crowded beds, where seedlings are badly blighted as soon as the moisture runs low. In dry, hot weather as much as 2 inches per week may be used.

Originally all watering was done with hose and spray; later the beds of larger trees were irrigated by flooding; now even the seed beds are usually flooded before the seeds germinate. Water will not stand on the surface for an appreciable length of time, so there is no danger of drowning young plants, and it is unnecessary to elevate the beds for drainage.

There is a danger of excessive watering, which consists in developing plants which, when set out, will not be able to withstand the drought conditions of the sand hills. It is true that the proportion of loss in the field does increase with the quantity of water given the trees in the nursery,[1] but, on the other hand, watering greatly reduces losses in the nursery. Hence it can not be said, without further experimentation, that it should be abandoned or materially decreased. This matter is now the subject of careful investigation.

[1] The results of an experiment begun in 1910, when 1,000 transplants were watered in different manners and continued in 1911, when 500 survivors of each lot were planted in the field, are as follows:

Frequency of watering.	Average quantity per week.	Transplants surviving in nursery, 1910.	Trees surviving in field, 1911.	Final survival.
	Inches.	*Per cent.*	*Per cent.*	*Per cent.*
None	None.	67.9	75.2	51.06
Biweekly	1.00	58.8	73.2	43.04
Daily	1.75	63.9	71.8	45.88
Weekly	2.00	68.0	65.4	44.37

The "final survival" is the product of the percentages of survival in field and nursery. This test, which appears conclusive, ought to be repeated before it can be said that the disadvantages of watering are thoroughly proved.

NURSERY OPERATIONS.

FERTILIZING.

Although the soil of the nursery at first appeared to be abundantly fertile to support a good stand of small trees, its virgin fertility has been dissipated, first, by the mixing of the surface soil with the sterile subsoil; second, by watering, which has doubtless washed out a good deal of the mineral fertility; and third, by the action of the wind, which has to some extent moved the surface soil about. Within two or three years the lack of humus in the soil began to be felt, but it was not until 1908 that the use of manure for fertilizing was begun on a large scale. Prior to this time some experiments had been made with commerical fertilizers, such as dried blood, bone meal, and phosphate, but these had had no appreciable effect; possibly because they were quickly washed out of the sandy soil, more likely because they did not change its physical composition. Leaf compost has some advantage over manure, but is not obtainable at Halsey in large quantities.

The effects of the lack of fertility, and more particularly of the lack of water-holding material in the surface soil, showed in several ways: The trees were small and slender; the roots ramified to great distances in order to obtain sufficient moisture and nutriment, and, in hot, dry weather, as a direct result of insufficient moisture, the trees were blighted.

It was the physical composition of the soil that most affected tree growth. An analysis of the soil from a number of nursery beds, made at the University of Nebraska in 1905, showed that growth of the seedlings was but little influenced by the small quantity of humus in the soil, but that it was very directly controlled by the quantity of moisture-retentive clay.[1] The object in using manure, therefore, is not so much to add to the quantity of plant food, which may or may not be deficient, as to increase the water-holding capacity of the soil by changing its physical composition. A small quantity of clay would doubtless have about the same effect, and would be of considerable value if it could be placed entirely below the depth of cultivation, but experience has shown that clay in the surface soil increases the difficulty of handling the trees. The extensive use of clay, therefore, has not seemed advisable. This matter, however, will be experimented with further.

The proper quantity of manure to use depends, of course, on its state of decomposition and the length of time that the soil has been in use. At Halsey it has been the practice, when space would permit, to grow trees on the ground for one or two years, then to manure

[1] Good growth was found where the percentage of alumina was from 2.05 to 2.76, and poor growth where the percentage was from 0.76 to 1.01. In the sand hills a sample showed 0.84 per cent of alumina.

it with from 50 to 120 tons per acre and grow a soiling crop upon it for one season. The soiling crop, of course, not only nitrifies the soil, but breaks down the manure to a more usable form. Where seed must be sown on ground freshly manured there is the possibility that an excess[1] of manure will cause the soil to dry out or that the plants will "burn" or will suffer from parasites. This latter danger, however, is not necessarily a result of fresh manure. No damage seems to have resulted from using manure just before transplanting.

Cow manure free from straw is the most easily prepared for use, and is the least likely to cause drying of the soil. It is obtained mainly from feeding yards, and after being broken up may be applied directly to the nursery soil. Horse manure is invariably mixed with straw, and is not used until it has composted for a year with sand, during which time it is turned two or three times and watered as often as necessary to prevent heating.

There is marked benefit from the use of stable manure followed by cowpeas as a soiling crop. In 1910 one bed which had had both manure and a soiling crop the previous year, and one which had only the soiling crop, were sown side by side. At the end of the first season the seedlings grown in the manured bed were from 1 to 2 inches taller than the others, and the difference still existed at the end of the second year in these beds. The sharply-defined increase in the average size of plants since manure began to be used is also clear evidence of the need for it in the sandy nursery soil, as shown in Table 7.

TABLE 7.—*Average sizes of 2-year-old seedlings at the end of various years.*

Year.	Height.	
	Jack pine.	Yellow pine.
	Inches.	*Inches.*
1906	3.9	4.0
1907	3.7	3.5
1910	8.0	5.0
1911	7.5	6.0

The aggregate benefits of the fertilizers show in the more stocky character of the transplants as they now become ready for field planting. For example, the 1909 3-year-old yellow pine, transplanted after two years in the seed bed (2–1), were from 5 to 7 inches high and had, on the average, about four strong roots, from 14 to 16 inches

[1] This is especially damaging to young seedlings, which may not be watered as heavily as transplants. The exact quantity of manure which may safely be used on seed beds directly or shortly before seeding is now being carefully investigated. Should it be found that enough manure to keep the soil in good condition and to produce strong plants can not be used, biennial fertilizing and rotation between transplants and seedlings will probably be necessary because of the restricted area of the nursery.

long. Those used in 1912 were about 5 inches high and had, on the average, at least eight roots, seldom more than 12 inches long.

These facts tend to show that better nourished, and hence more vigorous trees, are being produced by the use of manures. The more numerous roots, confined to a smaller space, are likely to increase the success of field planting, because, while deep roots are desirable, they can not be handled without damage, and a few long roots are less likely to secure soil moisture for the tree than many short ones. It is probable, also, that the greater size attained by trees in the enriched soil will also reduce from three years to two years the time required in the nursery. This practically reduces the costs by one-third and proportionately increases the capacity of the nursery.

SEED SOWING.

Seed beds are established each year where the ground has been well fertilized the previous year and, when possible, where a soiling crop has been grown in addition. After the ground has been graded so as to be irrigable from a single ditch it is flooded for settling and then staked out in beds 4 feet wide, with 20-inch paths between. The beds are grouped in sections. Each section is about 50 feet wide east and west and about 160 feet long north and south. The sections are separated from one another by 5-foot windbreak fences designed particularly to check the winds from the west and northwest. In some places willows and other trees have been planted to take the place of the fence windbreaks, but as space in the nursery is becoming more and more precious, the wisdom of such planting seems doubtful.

The surface of the beds is very carefully smoothed and firmed, in order that the seeds may all be covered equally.

Before sowing the seed is coated with red lead to make it unattractive to birds and rodents. Red lead is effective for small seed, but is less so with larger sizes. However, seed destruction seems to become less common each year.

The seed is sown broadcast in sufficient quantity to make about 125 seedlings to the square foot. The quality of the seed, number of seed per pound, and expected losses affect, of course, the quantity used. One pound of yellow pine may be enough for from 30 to 60 square feet of bed, while one pound of Norway or Scotch pine seed may cover 100 square feet. As soon as it is sown the seed is covered as evenly as possible by sifting soil over it from a plasterer's sieve to a depth of from one-eighth to one-fourth inch. A light watering follows this covering, and if any seeds are uncovered by this sprinkling more soil is sifted onto them.

As soon as a bed has been sown it is completely covered with burlap, pegged down at the edges of the bed, so as to be in close contact with the soil. This acts as a mulch to prevent drying of the surface soil

and blowing out of the seed and insures the seed an equable supply of moisture, so that germination is rapid and even over the entire bed. Before germination shade frames allowing them only one-half of full sunlight are placed over the beds. These frames consist simply of long strips of slat or lath fencing rolled out on a pair of horizontal bars which are parallel with the sides of the bed and extend its entire length. These frames, not permanently fixed, and easily rolled up, are much more convenient than permanent high shade frames, because they do not interfere with plowing and grading and may easily be rolled back in the event of particularly cloudy weather. Since they are from 22 to 24 inches high, they do not have to be rolled back for weeding, as all of the 4-foot beds can be reached from the sides.

Broadcast seeding supplanted drill seeding in the Halsey nursery in 1909, when an attempt was made to increase the productiveness of the ground. Drill-sown seed germinates more slowly, but usually in the end more completely. The method, therefore, is more economical of seed and has the further advantage of making weeding easier and of making cultivation possible. Broadcast seeding has the advantage where space is at a premium, because from 125 to 200 seedlings may be grown per square foot where all of the ground is occupied as against 60 to 100 in drills. With plenty of water cultivation of seed beds is unnecessary.

The time required for germination depends largely on the weather. Germination is much slower in early spring than at midsummer, and too much water retards germination by cooling the soil. The most rapid germination ever recorded at Halsey was six days for yellow pine, in midsummer. In the unusually cool spring of 1912 yellow pine took 22 days; Scotch pine, 24 days; jack pine, 29 days; and Norway pine, 40 days.

Practically all seed sowing has been done at Halsey in the spring, or just as soon as possible after the early field planting, transplanting, and preparation of the ground. Frequently seed sowing has not been completed before June 15, though it is quite certain that the earlier seeding produces the larger plants by the end of the season. Very early seeding, however, subjects the plants to more danger from damping off.

Exhaustive experiments with fall seeding have not yet been made, but it seems to have good possibilities for both the Halsey and Garden City nurseries. Fall seeding of 1911, at Halsey, germinated just one month ahead of the earliest spring seeding of 1912, which could not be done until April 29. Should it prove as effective as it promises fall seeding will doubtless be adopted to relieve the work of the spring season and give the plants the longer growing season. The advantages and disadvantages of various seasons for seeding are now being determined.

CARE OF SEED BEDS.

During and after germination the surfaces of the beds are kept quite constantly moist. Formerly new seed beds were sprinkled once or twice each day, now all watering is done by flooding. The beds are weeded early in the season, because if weeds attain large size seedlings are almost certain to be damaged when the weeds are pulled. In broadcasted beds only hand weeding is possible. When seed was sown in drills it was possible to cultivate between the rows and to some extent remove weeds with a narrow rake.

The greatest danger to young seedlings is from the disease known as "damping off," which results from the attack of any one of several fungi, which enter the seed as soon as the coat is cracked in germination. Many seedlings are killed before they push above the ground, while all are subject to attack until several weeks old. The small and comparatively weak seedlings of jack, Norway, and Scotch pine are more susceptible to damping off than those of western yellow pine. At Garden City, where damping off has been even more serious than at Halsey, Austrian pine suffered more than any other species, while Corsican pine was practically immune. This disease has been the subject of a great deal of study, but it appears that at Halsey it may best be controlled by treating the soil at the time of seed sowing with a solution of sulphuric acid, consisting of three-fourths fluid ounce of the acid in a gallon of water, applied at the rate of one quart per square foot. All the soil, both below and above the seeds, must be treated and the beds must be watered quite frequently until germination is complete, in order that the solution may not become concentrated. The treatment may injure some seedlings, but it effectively prevents the disease, and the loss from the acid is inconsequental as compared with the loss from damping off. This acid treatment is not recommended for a different soil, but all of the common preventives, such as dry and sterilized sand on the surface of the beds, and sowing at various seasons, have failed entirely, so that, if this treatment is effective elsewhere, it will greatly simplify the nursery procedure.

The shade frames are kept over the seed beds during the entire first year, and many seedlings which otherwise would die from overheating or drought are saved. It seems probable that losses which were formerly supposed to be due to damping off are nothing more than the effects of drought. The shade frames make the moisture more equable and at least reduce the frequency of watering.

The size of seedlings at the end of the first season is shown in Table 8.

TABLE 8.—*Height of seedlings at the end of the first season.*

Species.	Height.
	Inches.
Western yellow pine	1 to 5
Austrian pine	1 to 2
Corsican pine	½ to 1½
Jack pine	1 to 5
Norway pine	½ to 1
Scotch pine	1 to 4

Until 1911 practically all transplanting was done with seedlings which had been two years in the original seed bed and were then retained in the transplant beds one year, making what is called a "2–1 transplant." Occasionally, trees have been transplanted at one year and kept in the transplant beds two years more; these are designated "1–2 transplants." Trees kept in seed beds two years require watering about once each week; yet, in spite of this generous use of water, it has not been possible wholly to prevent blight, due to insufficient moisture, or to prevent stunting, due to overcrowding. When blight occurs it can be accounted for only by the inability of the roots to take up the moisture as fast as it evaporates from the leaves. With greater root space this difficulty would probably be obviated. In general, shade frames were not used on second-year seed beds, but recent experiments where they have been used have shown that losses may be reduced. The whole question of the proper regulation of the shade will stand further investigation. The longer the regular shading is continued in the seed beds, the greater the losses in the transplant beds. This has been proved by experiments begun in 1911, which show that the extent of loss at any time from removing shade frames is about proportional to the length of time that the trees have been under shade. This points to the advisability of gradually reducing the quantity of shade and thereby hardening the trees.

TRANSPLANTING.

The first transplanting at Halsey was done in 1906, with the object of developing a more compact root system; that is, shorter and more numerous roots. The success of these first transplants in the field in 1907 was so great that practically no seedlings have been planted directly in the field since that time. Practically all transplants have been "2–1," or three years old from seed when used in the field after two years in the seed bed and one year in the transplant bed. Experiments with both younger and older stock showed this to be the best and most convenient size from all standpoints. However, progress in developing large trees from seed had been so good by 1911 that in that year 1-year seedlings were transplanted, and these, in turn, were planted out in 1912.

FIG. 1.—MAKING THE FIRST TRANSPLANT BED OF JACK PINE AT HALSEY IN 1906.

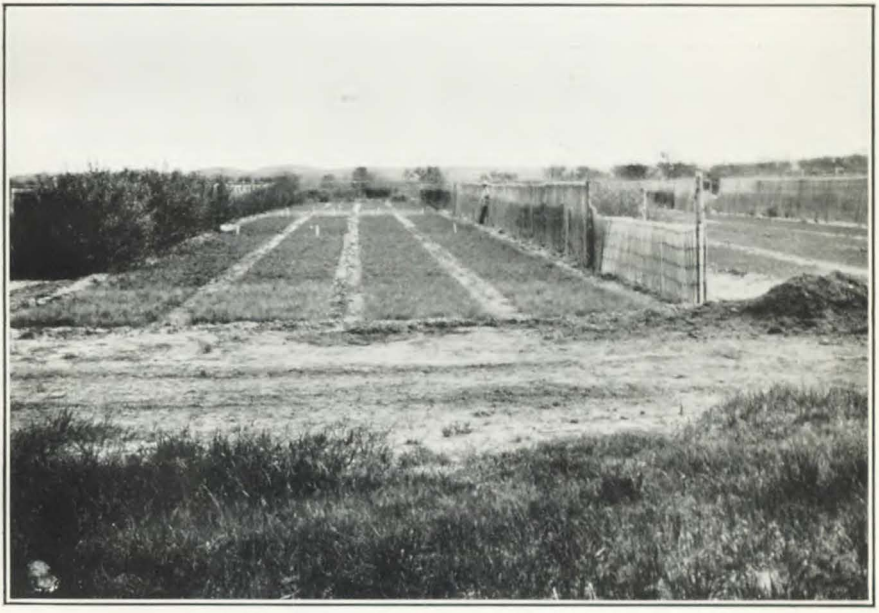

FIG. 2.—TRANSPLANT BEDS OF JACK PINE AT HALSEY IN 1912.

Much more economical of space than those shown in figure 1. Shelter fences and willow-hedge windbreaks.

FIG. 1.—DIGGING SEEDLINGS WITH TREE DIGGER, 1908.
Seedlings temporarily heeled-in on the right.

FIG. 2.—DIGGING SEEDLINGS WITH SPADES, 1910.
The seedlings are carefully packed in baskets between layers of wet burlap.

Ground for transplant beds is prepared much the same as for seed beds, except that it may have been freshly fertilized. It is deeply plowed and carefully leveled, but the beds are 6 feet wide, with 20-inch paths between, instead of 4 feet, as in the seed beds. Paths and beds are on the same level.

Seedlings are dug from their beds with spades. The Feigley tree digger has been tried at Halsey, and while it is cheap and effective for lifting seedlings, it has not always been possible to use it because of the scarcity of work horses. The contrivance does nothing more than lift the entire body of soil in which the roots are located and drop it again, thereby loosening the mass so that the trees are pulled out without much loss of fine roots. It is simply a horizontal, sharp-edged wedge which is run under the trees at any necessary depth down to about 12 inches, taking a strip about 1 foot wide for the entire length of the seed bed. Its disadvantages are that it is difficult to guide accurately, and hence may come too near the surface and cut off the roots too closely. In so far as it cuts merely the tips of the roots it probably does no damage, since root pruning, while not practiced at Halsey, has been used a great deal elsewhere. The digger also loosens the soil to such an extent that the trees must all be taken up very quickly, and since its economic rate of operation is considerably faster than transplanting, some extra labor is required to heel in the seedlings temporarily. Yet with these disadvantages it undoubtedly effects a saving in the cost of transplanting.

After being loosened with the spade the seedlings are lifted, and the main body of soil shaken from the roots. Great care is taken, however, to make sure that the fine soil particles are left adhering to the roots and that the finer roots are not broken. Formerly it was the practice to transport trees, not only between the nursery and field, but within the nursery, in buckets or tubs of water. This not only washed all soil from the roots, but also washed off the fine rootlets. At present trees are placed, even for short transportation, in baskets or boxes lined with burlap and moss. They are thus kept constantly moist, but are not washed. If seedlings can not be used at once in the transplant beds they are heeled in; that is, placed with their roots in a layer against the wall of a trench, which is then filled. If the seedlings are to be heeled in for some time their tops are covered with a mulch of straw.

The transplant crew consists of five men; two of them "thread" seedlings, one makes trenches, and the other two plant the trees in the trenches. The threading process consists in fitting the seedlings into notches on a "transplant board." The board[1] is 6 feet 3 inches long, with notches 1 or 1½ inches apart and ⅛-inch or more

[1] Full description of this board, the threading table, trencher, and tamper may be found in Forestry Quarterly, vol. X, no. 1, March, 1912.

wide, according to the spacing desired and the size of the stems to be fitted into the notches. When all notches have been filled with seedlings the latter are held in place by a thin strip of wood fastened over the stems. The threading is all done on tables, which have shields to protect the trees from the drying wind.

The trenches are made with a special tool, which has a heavy blade 26 inches long and 7 inches wide, and a handle. It is handled as a heavy spade would be in heavy soil; the weight of the worker is thrown on its upper edge, while the handle is moved back and forth and the blade worked into the soil, to a depth of from 6 to 10 inches, depending on the length of the roots of the seedlings.

The transplant board is placed on the edge of the trench thus made, with the roots of all the seedlings hanging in the opening. The two men engaged in planting then break in the walls of the trench with a tamp which packs the soil against the roots. When this has been partly completed the transplant board is taken away, and the earth is brought up to the level of the surrounding ground. The trenches may be 5 or more inches apart, according to the space desired between rows in the transplant beds.

The crew of five men may transplant 20,000 2-year seedlings per day or 16,000 1-year seedlings. The latter are more difficult to handle because they are smaller. For this reason it is doubtful that 1–1 transplants of such species as Norway pine are as cheap as older ones. Not only is a greater time required for transplanting, but some trees will be lost by being covered with soil at the time of transplanting or later. However, some economy for the nursery as a whole will have been gained if the plan of closer spacing, tried in 1912, is successful. A spacing of 1 by 5 inches was used experimentally for 1-year seedlings, while in the past, with 2-year seedlings, 1½ by 6 inches has seemed necessary.

Transplant beds are weeded and watered as carefully as seed beds. In addition, they are cultivated after each watering, a 2-toothed rake being used to scratch between the rows. Shade has not been used on transplant beds and probably will not be unless it is found necessary as a part of a gradual hardening process by which the water supply will be reduced somewhat, and the trees are given a very light shade.

A year in the transplant beds does not materially increase the height of most species, but makes them much sturdier. Thus a 2-year seedling is taller and much more slender than a 1–1 transplant if given equal opportunities for growth. The transplant, however, has a much better proportion of roots to top. The breaking of the longer roots at the time of transplanting seems to have the effect of stimulating the growth of a number of short roots, just as damage to the leader of a tree's stem will induce the growth of a number of branches.

While the average of yellow pine and jack pine 1–1 transplants are large enough for field planting, it may be necessary at the time of transplanting to separate the smallest of the seedlings and to give these two years in the transplant beds. The largest of the transplants are not so well proportioned as to tops and roots as the medium-sized ones and hence are less valuable for planting. The ideal tree for sand-hill planting has roots at least one-half longer than the top.

DIGGING AND PACKING.

Trees are removed from the transplant beds in the same manner as from seed beds, except that they are spaded up a row at a time, and as many of the long roots as possible are saved. As soon as they are loosened from the soil the trees are packed in planting baskets, in which there are several double layers of burlap padded with moss. Between each two layers a comparatively thin layer of trees is placed, so that, without making the pads very wet, all of the roots may be kept moist. By retaining the fine soil which naturally adheres to the rootlets a closer contact between the roots and the new soil of the hills is assured.

For shipping, trees are now always packed in slatted crates. The roots are all placed at the center of the crate, with abundance of moss between layers, and the tops point outward and are freely aerated. This practically prevents any heating, and the only thing to be feared is the lack of moisture as a result of delayed shipments.

FIELD PLANTING.

SPECIES.

SPECIES FOR THE NEBRASKA SAND HILLS.

Following the establishment of the station and nursery at Halsey, in the fall of 1902, some jack pine was immediately planted. This species was selected because of its well-known adaptability to the sandy soils of the Lake States, and the success attained with it on the Bruner[1] plantation. Experience has shown that the first choice was a wise one. Some 70,000 seedlings were pulled in the forests of Minnesota and planted at Halsey in the spring of 1903. Of this number 15 or 20 per cent were living three years later. The trees were from 2 to 5 years old when planted, and it is probable that a greater degree of success would have been attained if only the younger ones had been used. As it is, the survivors of this group are now the leaders of the entire plantation. In nine years they have attained heights of from 6 to 11 feet.

At the same time, 30,000 forest-pulled seedlings of western yellow pine, from the Black Hills, were planted. These failed entirely, and

[1] Four miles west of Swan, Holt County, Nebr.

the same fate befell extensive broadcast sowings of red cedar, jack pine, western yellow pine, and Colorado blue spruce.

The first planting of the nursery-grown yellow pine in 1904 was partially successful, in spite of the very difficult sites which were selected. One-year-old seedlings planted in 1905, on steep, cool, moist, north slopes, have succeeded, though for several years it seemed a question whether they would rear their heads above the grass. Western yellow pine is slow in gaining a foothold, and small trees may not make any appreciable growth for two or three years, yet they will retain life. Then, if the roots have succeeded in making a place for themselves in spite of the grass, vigorous growth begins. Jack pine, on the other hand, always establishes itself quickly and soon obtains enough root and crown space to give it an advantage over the native vegetation in the struggle for moisture and light.

By 1906 jack pine and western yellow pine had proved their worth. While no other species had been so thoroughly tested, Douglas fir, blue spruce, and other trees from the upper slopes of the Rockies had been tried in the nursery and, because of the little success in growing them from seed, they were abandoned.

Scotch pine was first planted in 1907. The plantation was on the gentle north slope which bore a heavy stand of bunch grass and was not very successful; but the persistence of some of the trees, which were of imported stock, clearly indicated the value of the tree for sand-hill planting. In 1908 and 1909 this species was tried again with stock grown at Halsey, and each year promised greater success.

Austrian pine was first tried in 1909 with seedlings brought from the east. It did not then, and has not since, shown any qualities that fit it for sand-hill planting. Possibly this is because all stock so far used has come from more humid regions. While the seedlings show great vitality and ability to resist drought, they are, even more than yellow pine, slow to gain a foothold.

Norway pine, a tree of the sandy soils of the Lake States, was tried on a small scale in 1909, and more extensively in 1910, with Halsey grown stock. The 1910 plantation on north slopes was very successful, and the trees are now making rapid growth.

An effort was made, in 1909, to systematize the arrangement of species in accordance with topographic features. Four sites are recognized—ridge, south slope, bottom, and north slope. The characteristics of the four main sites and the reasons for planting certain species on them are as follows:

(1) The ridge type has a very sandy soil, is most exposed to wind, bears the lightest vegetation, and has a low but very even moisture supply. Yellow pine seems best adapted to the ridges, because experiment has shown that it does not suffer from summer winds. The evenness of the moisture supply favors the slow-growing seed-

lings, because some moisture is available, even after other sites have become dry.

(2) The south slope is the warmest of the sites, because it receives the direct rays of the sun. The soil is usually a loose sand, very insecurely held by vegetation. The snow drifts to these slopes more than to any others, so that moisture conditions are good in the spring. Jack pine grows well here, because it starts earliest in the spring and is able to get established before the moisture is dissipated.

(3) The bottom type has the heaviest soil and bears the heaviest vegetation, so that, although it collects some moisture from the slopes, this is soon lost unless the vegetative growth can be checked. Yellow pine succeeds well if planted in wide, shallow furrows. The problem of obtaining success here without too great expense in the preparation of the ground is one of the most difficult yet to be solved. On the whole, the reason for planting yellow pine rather than any other species is that the tree, if it succeeds at all, is capable of making the best use of the fertile soil and can stand the heat. If Austrian pine should be planted at all, this is the best site. Of the hardwoods, green ash would doubtless succeed if it could be kept free from borers.

(4) The north-slope type is cool and moist, but usually carries a heavy cover of grasses and shrubs, and, not infrequently, belts of sand-hill willows where there is an imperceptible seepage from the soil. This site presents the least difficulty in planting. Almost any species is assured of a favorable start, and here yellow pine makes its most rapid growth. However, frost leaves the ground late, and since the soil is constantly cool it has been thought that a species demanding less heat might outstrip the yellow pine. Scotch pine, because of its northerly origin and known adaptability to coolness and moisture, has been chosen for this site. Its height growth in the past three years has considerably exceeded that of yellow pine. Norway pine, with characteristics similar to those of Scotch pine, has not been thoroughly tried on north slopes, but from present indications will have a place there if it can be successfully grown in the nursery.

Generally speaking, however, these distinctions as to site are matters of convenience rather than of necessity. Except that jack pine is by far the best tree for south slopes and that Scotch pine has succeeded only on north slopes, it should be understood that the species may be planted where it is most convenient.

SPECIES FOR THE KANSAS SAND HILLS.

The conclusions as to the adaptability of various species to the Kansas sand hills are not as definite as those for Nebraska. In the first place, the planting there has been in progress for a much shorter time.

Planting was begun in the spring of 1906, with 2-year seedlings of yellow pine and 1-year seedlings of honey locust, osage orange, Russian mulberry, and red cedar. Twenty-seven per cent of the yellow pine and 32 per cent of the honey locust survived the first season, but the other species failed. A number of these first yellow pines still persist and give clear evidence of having established themselves permanently, though they are so scattered that their struggle with native vegetation has been continuous, and they have, therefore, attained a height of only about 2 feet.

Various experiments have been made with black locust, green ash, elm, and jack pine. Up to 1911 it appeared that the hardwoods held greater promise than the conifers, because of the greater ease with which they could be grown in the nursery, the smaller degree of care required in handling, and their more rapid establishment in the soil. However, an extreme drought in 1911 killed all but the most resistant of the newly planted trees. On the basis of these drought conditions the various species may be classified as reliable or unreliable, the trees in each group being named in the order of their value:

Reliable species.	*Unreliable species.*
1. Green ash.	1. Jack pine.
2. Yellow pine.	2 Black locust.
3. Honey locust.	3. Cottonwood.
4. Red cedar.	4. Osage orange.
American elm.[1]	5. Hardy catalpa.
	Austrian pine.[2]

Only one hardwood, green ash, made a showing equal to that of yellow pine.

Because there are no distinct ridges and valleys in the Kansas sand hills, the division of the planting area into types does not seem practicable. In general, however, the hardwoods should be planted in the lower ground where the soil is heaviest, and the conifers in the lighter soil of the high ground. In the area now being planted even this differentiation is neither practicable nor necessary.

The one striking feature of the planting in Kansas is the failure of jack pine. This may be attributed partly to damage by rodents, but is in a large measure due to the greater warmth of the region as compared with Nebraska, the more extreme drought conditions which may prevail, and the greater severity of the summer winds. Jack pine evidently does not resist these influences. Green ash, among the hardwoods, and yellow pine, among conifers, have shown, on the other hand, the most surprising resistance. Green ash survived the summer of 1911, even after most of the leaves had been completely desiccated.

[1] Not yet tried in field planting. Value assumed from general knowledge.
[2] Not yet tried with stock of suitable size. Exact value not determined.

KIND OF STOCK.

CONIFERS.

As already stated, the first planting of conifers at Halsey was with forest-pulled seedlings, which have never been successful except under the most favorable climatic conditions. The next planting was with 1 and 2 year old seedlings grown in the local nursery. These were obviously too small; there were not enough roots, and these were too long to be handled conveniently. The trees succeeded only in the most favorable situations, north slopes. However, the use of 2-year seedlings was continued through 1906, when the percentage of success on east and south exposures was from 18 to 41, and on northerly exposures from 50 to 68.

Steady improvement ensued from the first use of transplants, in 1907. Tables 9 and 10 show the results of experimental planting in 1909, in which stock of various ages was used, and indicate the causes of earlier failures.

TABLE 9.—*Survival and growth of yellow pine of various ages, in bottom type.*

Age and treatment.	Proportion of thrifty trees left.			Average height, fall, 1911.	Average current growth, season of 1911.
	1909	1910	1911		
	Per cent.	*Per cent.*	*Per cent.*	*Inches.*	*Inches.*
3-1 transplants	88	73	69	7.7	1.9
2-1 transplants	82	76	69	7.1	2.1
1-1 transplants	50	46	36	5.5	1.5

TABLE 10.—*Survival and growth of Scotch pine of various ages, on north slope.*

Age and treatment.	Proportion of thrifty trees left.			Average height, fall, 1911.	Average current growth, season of 1911.
	1909	1910	1911		
	Per cent.	*Per cent.*	*Per cent.*	*Inches.*	*Inches.*
2-1 transplants	81	69	65	12.0	3.4
1-1 transplants	63	53½	34½	7.9	2.4
2-year seedlings	7	5	3	10.3	2.3

From these tables it is apparent that the 2–1 transplants are to be preferred as against the younger or untransplanted stock. While the oldest yellow pines give slightly better results, it is thought that this will not be apparent after two more years; moreover, their additional cost precludes their use. The use of 1-year seedlings such as have proved fairly successful, under favorable climatic conditions, in the white-pine planting in the East, is wholly out of the question.

In the past, three years have been required at Halsey for the development of a suitable plant, but it is now thought that two years will

suffice because of the steady improvement of the soil through fertilizing and because of the unstinted use of water. In Kansas, however, it is possible that none of less age or less perfect root development than the 2–1 transplants can be used profitably. Even older stock may prove cheapest in the end, but this matter has not had a conclusive test.

HARDWOODS.

Practically all hardwoods used in both Nebraska and Kansas have been grown in the nursery only one year. The soil of the Garden City nursery produces such vigorous growth that even the 1-year seedlings of the locusts have to be pruned on both the stems and roots for convenient handling. It would be impracticable to use older seedlings, and, because the roots sprout readily in the field, it is wholly unnecessary to transplant hardwoods in the nursery for root development.

METHODS OF PLANTING.

Four methods of planting have been tried successively in both the Nebraska and Kansas sand hills. These are the "slit," "square-hole," "cone," and "trencher" methods.

THE SLIT METHOD.

The slit method of planting was the first to be tried in this work; it has been much used in forest planting because it is cheap. It seemed especially desirable in the sand hills because the soil is loose and light and free from stones. An ordinary spade, with 7 by 12 inch blade, is used, and may be light or heavy as the worker prefers. The blade is pushed straight down into the soil to its full depth, the handle is moved back and forth to open up a wedge-shaped hole, and the blade is then withdrawn. Taking a tree in the left hand, the planter whisks its roots into the hole, and with the right hand and right foot again inserts the spade parallel to the original insertion, and about an inch from it to close the original opening and to secure the tree in an upright position. While a new opening is made, it is readily closed by several successively shorter strokes with the spade and finally by pressing with the foot.

The principal disadvantages of this method are: The inelastic depth of the slit; lack of spreading of the roots, which may lie in a cordlike or slightly flattened mass; and the danger, in rapid work, that the tips of the roots do not reach the bottom of the slit. Careless workmen actually have left the tips of the roots out of the ground and the whole root mass in the shape of the letter U. This is not, of course, an insuperable argument against the method, which has strong merits.

FIG. 1.—THE SLIT METHOD OF PLANTING IN FURROWS, KANSAS FOREST, 1906.
The picture gives a good idea of the rolling character of the lands.

FIG. 2.—RESULTS OF THE SLIT PLANTING OF 1903-4 AT HALSEY, WITH FOREST-PULLED SEEDLINGS; A SCATTERED STAND OF JACK PINE.

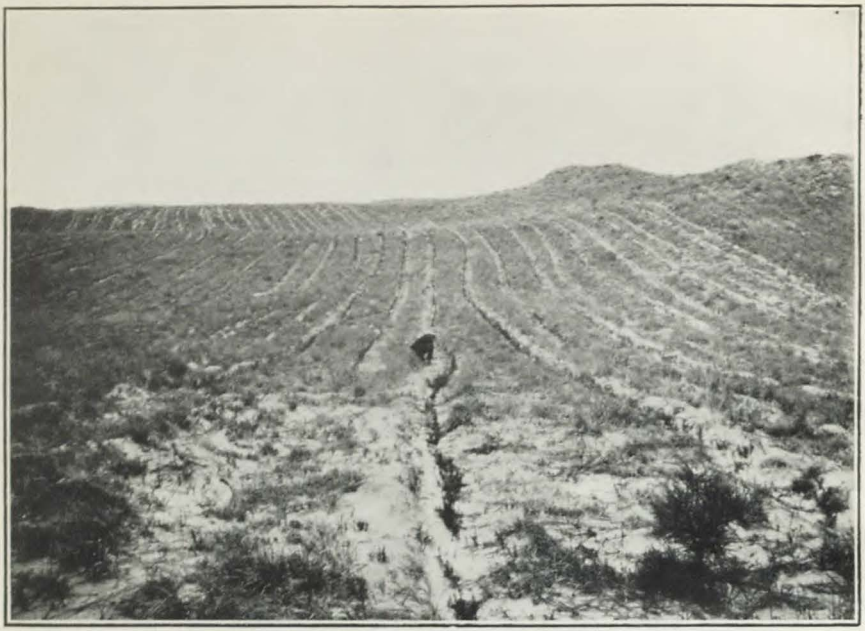

FIG. 1.—RESULTS OF THE TRENCHER PLANTING OF 1911 AT HALSEY, WITH LOCALLY GROWN TRANSPLANTS.

Fully 90 per cent of the jack pine is growing in every furrow.

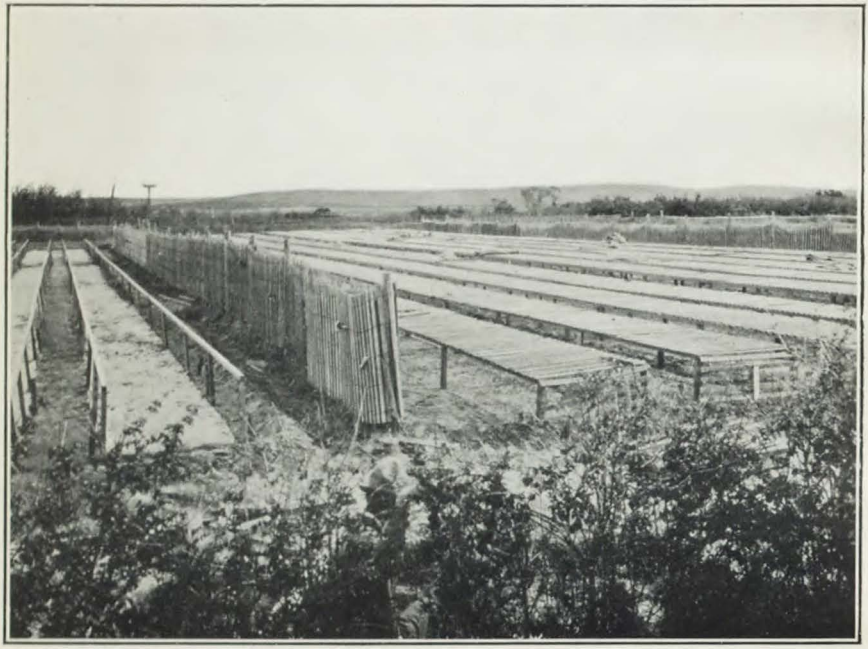

FIG. 2.—SEED BEDS BROADCASTED IN 1912.

The surfaces of new beds are protected by burlap, and beds in which germination has begun are covered by low shade frames, and the burlap is removed.

It was used at Halsey for several years, and while a part of the early failures may be accredited to the method, not a little was due to carelessness of individual workmen, as shown by the differences between adjacent rows in the plantations. At any rate, it did not appear to be adapted to sand-hill planting, because it did not give the roots enough opportunity to obtain moisture.

The slit method was practically abandoned in 1908 for the square-hole method, which had first been tried the previous year.

THE SQUARE-HOLE METHOD.

The square-hole method of planting makes use of a hole a foot deep and 7 inches square. Because of the looseness of the soil the hole may be dug with from three to five strokes of the spade, the earth being piled on one side. A second man follows the digger, setting the trees by simply holding their stems at the proper height in the center of the hole and pulling the earth in around the roots with the other hand. This method, in the hands of the average workman, has all of the disadvantages of the slit method, except that there is little danger of the root tips being left near the surface of the ground. Since the digger has no knowledge of the actual size of the tree to be planted in any individual hole, he makes all holes of a certain depth. While many are deeper than necessary, not one is deep enough for those trees which, by good fortune, reach the field with long roots, which have to be coiled in the bottom of the hole. Furthermore, there is nothing to prevent all of the long roots being crowded together into a cordlike mass when the earth is thrown in around them.

Therefore, in spite of the greater expenditure which was being made to give the trees careful planting, it was soon found that the square-hole method was not materially improving the results.

THE CONE METHOD.

As a result the cone method was tried, and with great success. It is similar to the square-hole method with this addition—after the hole has been dug the planter makes a mound or cone of earth in the bottom of the pit, spreads the roots around this cone, and weights them in place with a small quantity of earth before pulling in the larger mass. This keeps the roots separate and gives them access to greater soil space. There is a reduction of loss immediately after planting, but later, when the roots of grasses and other native vegetation begin to crowd into the space needed by the tree, its advantages disappear, and if the tree is not firmly established nothing can save it.

Table 11 compares the success attained with the three methods of planting in 1909.

TABLE 11.—*Results of slit, square-hole, and cone methods of planting, Nebraska, 1909*

Method.	Proportion of thrifty trees left.					Average height of trees.
	Fall, 1909.	Spring, 1910.	Fall, 1910.	Spring, 1911.	Fall, 1911.	Fall, 1911.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Inches.*
Cone	70	51	47	45	40	6.4
Square hole	36	26	25	17	15	5.6
Slit	42	36	36	36	33	5.4

The immediate advantage of the cone method is plainly shown. It is shown no less plainly that this does not prevent the trees from ultimately succumbing to the competition with native vegetation. Therefore, considering the much greater cost, the cone method does not appear to be justified. Making a definite calculation, with trees at $8 per thousand at planting time, the relative cost of establishing a plantation to the age of 3 years is as follows: Slit method, $4.34; square-hole method, $10.70; and cone method, $7.20.

The slit method involves greater expense than the others for trees alone. But in cost of trees plus labor it is the cheapest, and this must be the final basis of comparison. This pointed to the necessity of developing the slit method by trying to eliminate its bad features.

THE TRENCHER METHOD.

The trencher method, which is nothing more than a mechanical form of the slit method, has been developed since 1909. This consists in turning back a shallow furrow with an ordinary breaking plow or with a sidehill plow. In this furrow the trencher plow is run, to make a V-shaped trench from 8 to 10 inches deep and about 1½ inches wide at the top. The trees are planted at intervals in this trench, much the same as in slits, using the heel or a spade to press the walls of the trench against the tree roots. The trench has one great advantage over the slit, because there is more space to whisk the roots to the bottom. Moreover, it is rapid and cheap; six horses with plow and trencher prepare the ground for from 10 to 12 planters. With a horse's labor calculated in the ratio of two-fifths of a man's labor, the average day's planting per man by the trencher method is 1,061 trees, as against 215 for the cone, 500 for the square-hole, and 1,038 for the slit method. The trencher planting of 1911 was highly successful and showed from 90 to 92 per cent of thrifty survivals at the end of the first year. While this was due in part to favorable seasonal conditions, there seems to be no doubt but that a cheap and efficient mechanical method of planting may be developed. The trencher method is certainly the least expensive. Where cost is not a consideration, the cone method is the one to use.

PLANTING AFTER PLOWING.

As a result of the experience of farmers whose fields were literally blown away after one or two years of cultivation it was not considered advisable to plow the ground completely before planting in the sand hills. Much of the original slit planting was, therefore, done in the sod, while some was done in single furrows, spaced from 4 to 6 feet apart, on contours.

This furrow destroyed some native vegetation and gave the newly planted trees a little better opportunity for obtaining moisture, but allowed the trees to be covered by sand, which, when the sun shines directly on it, becomes so hot as literally to bake anything in contact with it. For some time, therefore, the desirability of furrows was in question. Now, however, it is proved that they are neither necessary nor desirable where the sand is loose and likely to be blown over the trees. On the other hand, they are desirable and perfectly safe where the sod is heavy and the soil firm.

In 1909, for the first time, a small area was thoroughly plowed before planting. The area was selected in a bottom situation where the sod was very heavy. There was no blowing of the soil during the first year, though the ground was once cultivated during the summer. At the end of the season 92 per cent of the trees planted were living in this area, as against 80 per cent in furrows and 57 per cent where the sod had not been broken. By the end of 1911, however, the proportion of survivals in the plowed ground was considerably less than in the other two situations. This was partly due to the destructive work of pocket gophers in the plowed ground, and partly due to the invasion of weeds which appeared to demand even more moisture than the native grasses and herbs.

Until further tests are made on a large scale the exact effect of plowing for pine plantations can not be known. Even though plowing and subsequent cultivation have a distinct effect in increasing the proportion of survivals in Nebraska, it is doubtful if the expense will be warranted. In Kansas, on the other hand, experience indicates that only by thorough cultivation of the ground can young trees be brought through the first year, if that happens to be a dry one. Even there it is possible that double furrows, some distance apart, subsequently cultivated as with listed corn, may be effective and much safer, because of the smaller danger from blowing of the soil.

It is quite certain that the ground should never be plowed except where the sod is dense and the soil heavy, and not even furrowed where the sand is loose on exposed ridges and south slopes.

FIELD SOWING.

As early as the spring of 1903 direct seeding, or the sowing of seed in the field where the trees are to stand, was attempted. The seed was simply broadcasted, and nothing came of it. Further sowing of yellow pine was tried in 1904, but with corn planters to get the seed into the soil. Little evidence of germination was found, and no trees grew. The total failure may be ascribed largely to the activities of field mice and other rodents, which, in spite of the red-lead covering which was placed on the seed, had begun uncovering and devouring them within three days. The idea of poisoning these rodents had not at that time been developed. No success was attained with direct seeding on the Nebraska Forest until 1909, and then on such a small scale that it has had no practical influence. In that year seed of yellow, Scotch, and jack pines were broadcasted on the heavy litter under sand-hill willows and thoroughly raked in. Within a short time seedlings appeared, and while all species germinated, only the yellow-pine seedlings survived. These, at the end of the third summer, made a stand of about 850 seedlings per acre. Considering that five seeds were sown to the square foot, this is a very poor showing. However, conditions appear to be so favorable under the willow clumps that the possibility of obtaining a stand by sowing in prepared seed spots is being investigated. So far, rodents and birds seem to be the chief agents of failure.

In Nebraska direct seeding will never take the place of planting on any but the most favorable sites, and possibly not there. It holds no promise at all for the Kansas sand hills.

EFFECT OF CLIMATE ON TIME OF PLANTING.

Those climatic conditions of the sand hills which are unfavorable to tree planting can not be changed as a whole, though as planting progresses trees which are already established will temper the wind to those newly planted. On the other hand, the favorable climatic conditions of early spring can be used to advantage, and the trees can be well established in their new conditions before the summer dry weather sets in. The dry periods are usually of rather short duration, but are very trying. To take advantage of the spring season planting is begun just as soon as the frost is out of the ground, especially on south slopes, which dry out very rapidly. The effectiveness of early planting is shown not only by the generally greater success with it in the last two or three years, but particularly by the good results attained on south slopes, which, it was at first thought, would be impossible to plant at all.

Fall planting has been abandoned because of the lack of snow, which leaves the newly planted trees exposed to drying winds for

FIG. 1.—BLACK-LOCUST SEEDLINGS, SHOWING DEVELOPMENT ATTAINED BY ROOTS AND TOPS IN ONE YEAR AT GARDEN CITY NURSERY.

FIG. 2.—HARDY CATALPA SEEDLINGS, SHOWING DEVELOPMENT ATTAINED BY ROOTS AND TOPS IN ONE YEAR AT GARDEN CITY NURSERY.

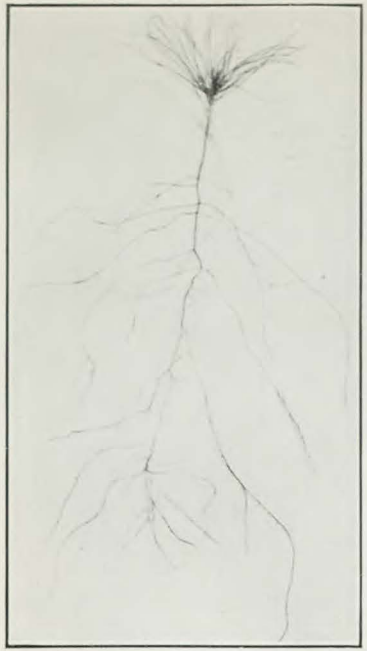

FIG. 1.—TWO-YEAR-OLD SEEDLINGS OF JACK PINE, AS GROWN AT HALSEY IN 1905.

Roots 16 inches long.

FIG. 2.—TWO-YEAR-OLD SEEDLINGS OF JACK PINE AS GROWN AT HALSEY IN 1912.

Showing root development in a smaller space; roots 11 inches long.

FIG. 3.—THREE-YEAR-OLD TRANSPLANTS OF JACK PINE AS GROWN AT HALSEY IN 1912.

Showing the great increase in number of roots over the seedlings formerly used for field planting.

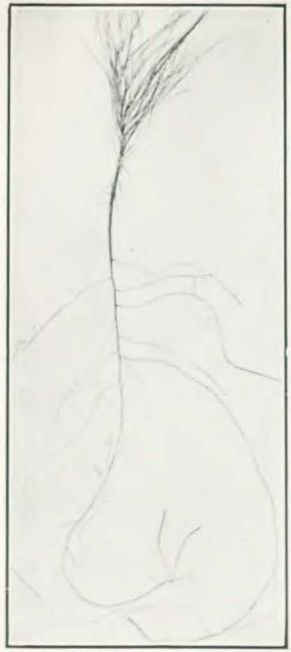

FIG. 1.—TWO-YEAR-OLD SEEDLING OF YELLOW PINE AS USED FOR FIELD PLANTING AT HALSEY IN 1905.

Roots more than 20 inches long.

FIG. 2.—TWO-YEAR-OLD SEEDLINGS OF YELLOW PINE AS GROWN AT HALSEY NURSERY IN 1912.

Roots 10 or 12 inches long when transplanted.

FIG. 3.—THREE-YEAR-OLD TRANSPLANTS OF YELLOW PINE AS GROWN FOR FIELD PLANTING AT HALSEY IN 1912.

Roots numerous, 13 inches long.

several months before they are able to begin taking up moisture. Even very early fall planting, which has given the trees opportunity for root growth before cold weather, has yielded unsatisfactory results.

ENEMIES OF PLANTATIONS.

Forest protection is everywhere recognized as one of the chief functions of forestry, and especially so in the United States with its virgin forests, but it is nowhere of greater moment than in the sand hills. Almost every kind of forest enemy has been encountered since planting was begun in Nebraska. Of the enemies of the embryo forest nothing can be considered of so great import as fire.

FIRE.

Probably for centuries the prairie fire has been the expected, and sometimes the desired, thing in the sand-hill region. Prairie fires temporarily improve grazing conditions by destroying the old grass, which has no forage value, and making room for a more vigorous growth of the new grass. But they undoubtedly have done the sand hills permanent injury by destroying the humus which otherwise would have collected in the soil and would have improved its composition and productivity. The most destructive prairie fires come in the early spring before new grass has sprouted. Even the lightest of fires destroys small coniferous trees, which burn readily, though jack pine at Halsey has sometimes recovered after a light scorching.

To protect the plantations properly requires constant care during the danger season and the preparation each year of plowed fire lines. As with most fire lines, these are valuable principally as a basis for back-firing and can not be depended upon to check a fire. For complete safety from outside fires all of the plantations are surrounded by double guards, consisting of two strips of furrows with a grassy strip between them from 60 to 100 feet wide, which is burned off annually. Then, there is the additional problem of protecting from fires which may arise within the plantation, either as a result of lightning or through the carelessness of laborers and hunters. This internal protection is afforded to the plantation as a whole by dividing it into tracts of 40 acres or more, separated by fire lines. While absolute protection is hard to achieve, the fire danger will decrease somewhat as the trees become older and more resistant and as the grass is shaded out. As soon as the trees become so large that they will not be broken off or browsed stock may be used to keep the grass down.

INSECTS.

The only destructive insect which has appeared in the Nebraska plantations is the Nantucket pine-tip moth (*Retinia frustrana*), which appeared in 1909. Similar insects had been noted in the Pine Ridge

forests as early as 1901.[1] Since 1909 it has increased very rapidly at Halsey, doing a great deal of damage to jack pine, and to a less extent to yellow pine. The larvæ of this moth bore into the young succulent shoots at the ends of the branches, hollowing them out for a distance of from 2 to 6 inches and usually causing the death of the shoot as far back from the tip as the boring goes. New growth is usually made at once from buds below the affected tip, but the natural leader on the main stem or side branch of the tree is destroyed, and with it the possibility of symmetrical growth. On those trees which have been attacked for two or three years such a large number of shoots have been formed to take the places of those destroyed that a "witch broom" is made. Should the pest become less abundant soon, the damage so far done will not work any permanent injury to the trees. Dr. A. D. Hopkins, of the Bureau of Entomology, United States Department of Agriculture, is authority for the statement that observations on this insect in the District of Columbia and vicinity since 1879 indicate that continued damage is prevented by natural enemies, and that only at comparatively long intervals is it very abundant and injurious. Two parasites have been found to attack this insect in the Nebraska plantation.

The sawfly[2] which is destroying pine in the Pine Ridge has not yet appeared at Halsey.

BIRDS AND RODENTS.

Pocket gophers are probably the next most damaging enemies of the young forest and kill a good many trees. Most of the damage is done immediately after planting, since the stirring up of the soil seems to attract these animals. The gophers are everywhere present, and have done some damage in each plantation each year, taking trees of as great height as 6 feet. The poisoning of these animals is not impossible, but it is slow and expensive work.

Sharp-tailed grouse and quail nip the buds, and rabbits cut off the tops of young trees. The harm from these injuries is that they retard growth, though in the Kansas sand hills so many trees were killed outright by rabbits in 1909–10 that it was necessary to protect the small planting area by a rabbit-proof fence. In this case the bark of yellow pine was taken off almost completely. It becomes less attractive after the trees have been out one season. Corsican pine was started in the Garden City nursery in 1910, principally because it was immune from rabbit damage.

[1] Forest Belts of Western Kansas and Nebraska, Bulletin 66, Forest Service, U. S. Dept. of Agriculture. 1901.

[2] A New Sawfly Enemy of the Bull-pine in Nebraska, M. H. Swenk, 24th Annual Report, Nebr. Agr. Experiment Station.

GROWTH.

The growth of the jack pines planted in the Nebraska sand hills has been just about the same as that of the Bruner plantation, described in Table 6, though the planting of 1903, with forest seedlings about 3 years old at the time of planting, is the only one old enough to be comparable. At the end of 1910—that is, after eight years in the hills—these jack pines had an average height of 7.54 feet and a maximum height of 10 feet. The trees have not been stimulated to height growth by crowding, as in the Bruner plantation, where they were spaced 2 by 2 feet, but since 1910 they have been making at least a foot a year in spite of insect damage. These facts indicate that the tree will, at least for a number of years, make good development. It can hardly be expected that jack pine will attain in the light soil of the sand hills more than its average height, about 60 feet.

From the planting of 1909, when, for the first time, the several species were planted side by side at Halsey, with stock of the same age (2–1 transplants) it is seen that jack pine makes better height growth in the early stages than any of the other species. This earlier supremacy may not be maintained. It already appears that yellow pine is capable of fully as rapid growth when once established, and the tree normally attains a much greater height. The comparative growth of the several species is shown by Table 13.

TABLE 13.—*Comparative growth of different species of pine in the Nebraska sand hills.*

Site.	Species.	Growth, 1911.	Total height, end of 1911.	Proportion of total height attained at sixth year.
		Inches.	*Inches.*	*Per cent.*
South slope	Jack pine		18.1	
Do	Yellow pine		6.3	
Do	Scotch pine		9.0	
Do	Norway pine		7.8	
Do	Austrian pine[1]		6.4	
Bottom	Yellow pine		6.4	
North slope	do		7.6	
Do	Scotch pine	3.4	12.0	28
Do	Yellow pine	2.1	7.1	30
Ridge	do	1.8	6.6	27
Do	Austrian pine[1]	1.6	6.9	26

[1] Austrian pine trees were 2-year seedlings at time of planting, hence are 1 year younger than trees of the other species.

Yellow pine is barely getting under way at six years, while jack pine is growing much more vigorously. Table 14 gives figures for older plantations of yellow pine and those for some of slightly greater age than in the Halsey plantations, grown naturally in the Pine Ridge region.[2]

[2] From "Forest Belts of Western Kansas and Nebraska," Bulletin 66, Forest Service, U. S. Dept. of Agriculture.

TABLE 14.—*Height growth of yellow pine at various ages.*

Situation.	Age of stock when planted.	Time in plantation.	Present age of trees.	Growth in last year.	Total height.	Proportion of total height attained in last year.
	Years.	*Years.*	*Years.*	*Inches.*	*Inches.*	*Per cent.*
Bottom	2	3	5	1.5	5.5	27
Do	4	2	6	1.4	8.2	17
Do	3	3	6	2.1	7.1	28
Do	4	3	7	1.9	7.7	16
North slope	2	6	8	5.7	16.6	34
Do	1	7	8	8.3	27.8	30
Flat	1	8	9	8.2	36.6	[1] 22
West slope	1	8	9	10.0	38.4	[2] 26
North slope	1	8	9	10.5	41.2	[3] 25
Crawford, Pine Ridge	.....	.....	10	4.5	28.8	16
Bordeaux, Pine Ridge	.....	.....	10	5.5	33.6	16
Belmont, Pine Ridge	.....	.....	12	8.0	37.2	21

[1] 76 per cent of leaders attacked by pine-tip moth in 1911.
[2] 45 per cent of leaders attacked by pine-tip moth in 1911.
[3] 25 per cent of leaders attacked by pine-tip moth in 1911.

It is thus quite evident that yellow pine is going to make excellent height growth in the sand hills when once established. The deep-green color of the trees and the long needles are other evidences of thriftiness. The well-established trees have more the appearance of those growing in the moist Black Hills region than of those in the Rocky Mountains proper.

The few examples given are sufficient to indicate the feasibility of growing forests in the sand hills. It is impossible to foretell the size that will be attained by yellow pine, or at what age the trees will produce merchantable timber. While the jack pine, because of its habitually scrubby character, may never attain to a size sufficient for saw timber, there can be little doubt but that the yellow pine will, and possibly, the Scotch pine. Yellow pine might well be grown as the major product, with jack pine as a secondary tree, in mixture to stimulate the height growth of yellow pine, and to be cut at an early age for fence posts and other small material.

Jack pine, in 20 years, should make one first-class and one second-class post per tree. These may safely be valued at 8 and 4 cents, respectively, or 12 cents per tree. Suppose, then, that 2,500 trees are planted per acre, at a cost of $8 per thousand. Of these, 80 per cent are jack pine and 20 per cent yellow pine. Suppose again, that 80 per cent of the jack pines and 60 per cent of the yellow pines succeed. The 1,600 jack pines, cut at 20 years, give a gross income of $192 per acre. This is sufficient to cover the cost of plantation, with 4 per cent interest, and protection at 10 cents per acre per year, and leave a net annual income of $4.87. The 300 yellow pines per acre are left, and being freed from interest-bearing debt, may be grown to almost any age with reasonable assurance of profit. While these are rough calculations and subject to error, it is not difficult to see that

the growing of timber on the sand hills, both for minor and major products, may be on a perfectly safe financial basis and may be putting the land to a considerably higher use than for grazing.

CONCLUSIONS.

In summing up the sand-hill planting it may be said that the 85 or 90 per cent of success attained in 1911, as compared with 5 or 10 per cent in the first planting, is due largely to improved methods in the nursery. Seedlings pulled in the forest should never be used in an arid climate, and even those which have been grown in near-by nurseries may not be sturdy enough to survive unless they have been once transplanted.

The inauguration of transplanting has had as much to do with progress as anything else. Sturdier trees are now being grown as the result of the generous use of organic fertilizers and the application of plenty of water to the seedling and transplant beds at the right time. Reduction in the amount of shading has also prepared the trees more fully for the sand-hill conditions.

Undoubtedly some of the first planting by the slit method did not sufficiently take into account the struggle which the trees would have for moisture. The improved results to-day, however, can not in any large measure be ascribed to new methods of planting, since the best results ever attained on a large scale have followed the use of the trencher, a mechanical means for making slits. The better stock now available may safely be planted with the trencher, in furrows, much as the first planting was done, but more rapidly and yet more carefully. Where small lots of trees are to be planted, and the question of initial expense is not so important as the obtaining of immediate success, the cone method of planting should undoubtedly be used.

Greater care in handling the trees, with the elimination of the water bucket as a transporting vessel, and the avoidance of long storage, either in storehouses or boxes, have assisted the work.

Undoubtedly, the most important single factor is earlier spring planting, which also makes possible earlier transplanting and earlier seed sowing. The conditions in the sand hills at the time when the frost leaves the ground are usually favorable. The soil is moist, and the trees are ready to grow. With each day the moisture is dissipated, the heat becomes greater, and the danger that the tree will become dried out before its roots can establish themselves in the new site, is greatly increased. With these facts recognized, it is certain that only exceptional and unusually damaging conditions can bring failure.

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